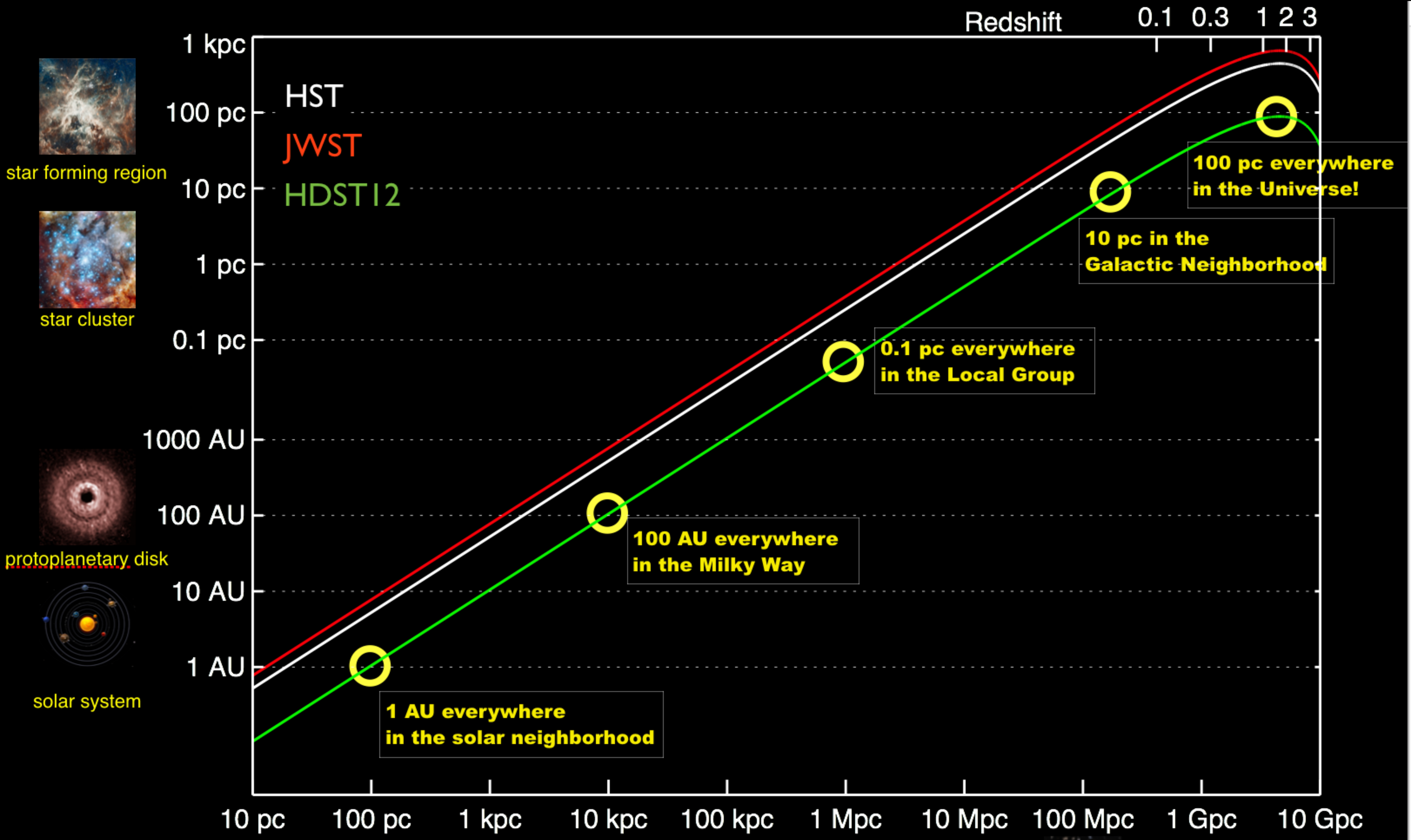
JOHN O'MEARA, SAINT MICHAEL'S COLLEGE

THE WHEN, WHERE, AND HOW OF GALAXIES WITH *LUVOIR*

BIG QUESTIONS

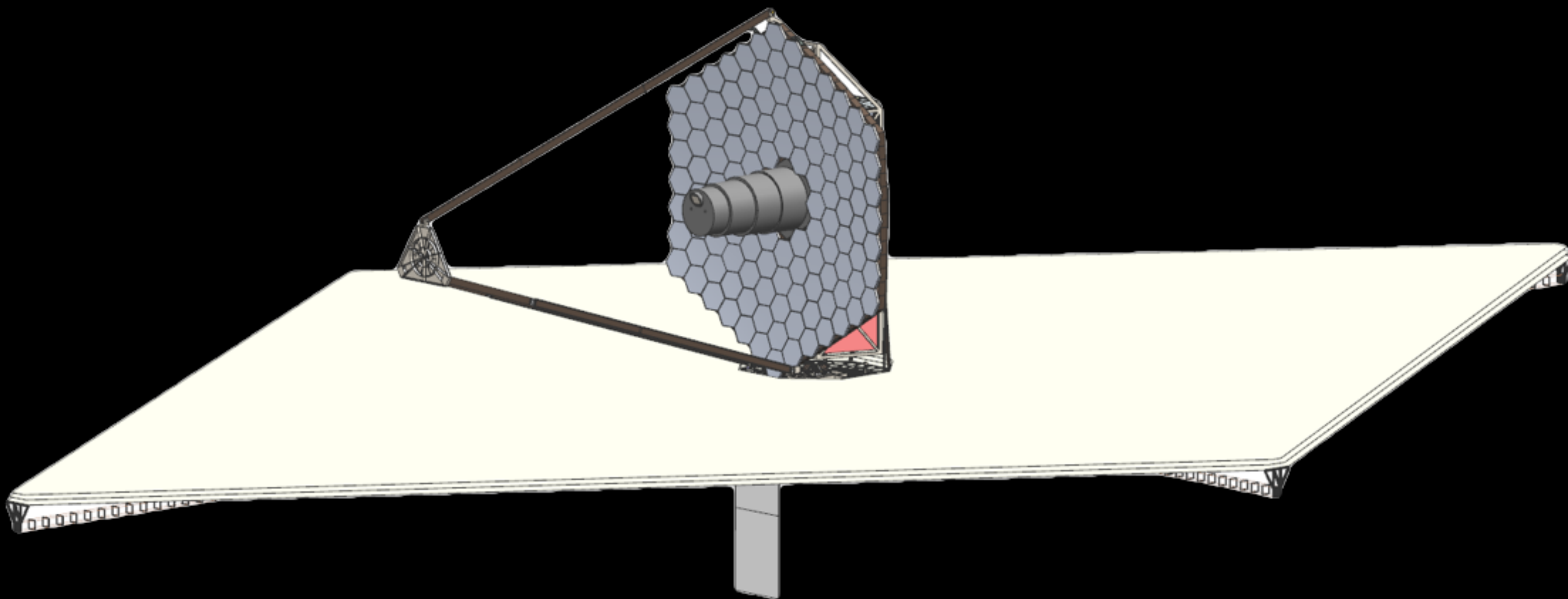
- How are galaxies assembled, and how do they fuel their stars?
- How does the Hubble sequence emerge?
- Do galaxies reionize the universe?

SO.....WHY LUVOIR?



Via the HDST report

LUVOIR ARCHITECTURE A



15.1 meter primary

LUMOS, HDI, Coronagraph, ONIRS, Pollux

HDI

HDI Technical Overview (1/2)

- Two-channel Imaging Instrument:
  - UV/Vis Imaging (200 nm - ~1.0 μm)
    - Diffraction-limited performance at 500 nm
    - Nyquist sampled at 400 nm
  - NIR Imaging (~1.0 μm – 2.5 μm)
    - Diffraction-limited performance at 1.2 μm
    - Nyquist sampled at 1.2 μm

- Each channel will contain a suite of spectral filters:
  - Narrow (R ~50-100)
  - Medium (R ~20-40)
  - Broadband (R ~3-5)
  - At least one slitless grism/prism option with R ~200-500

- Field-of-view: 2 x 3 arcmin
  - Both channels view the same patch of sky

Via M. Bolcar & HDI team

HDI

HDI Technical Overview (2/2)

- Exposure times:
  - For most extragalactic sources and stellar population observations:
    - Total observation times of up to 200 hrs.
    - Composed of many exposures of 500-1000 s each
  - High-speed photometry will require exposures of 50 – 100 ms
    - Will only be required over a small area of the focal plane array (perhaps a single SCA of the entire FPA)

- Dynamic Range:
  - Desire the ability to define a region of the focal plane with reduced sensitivity (or faster readout) for both astrometry and solar system observations

Via M. Bolcar & HDI team

HDI

HDI Special Modes :

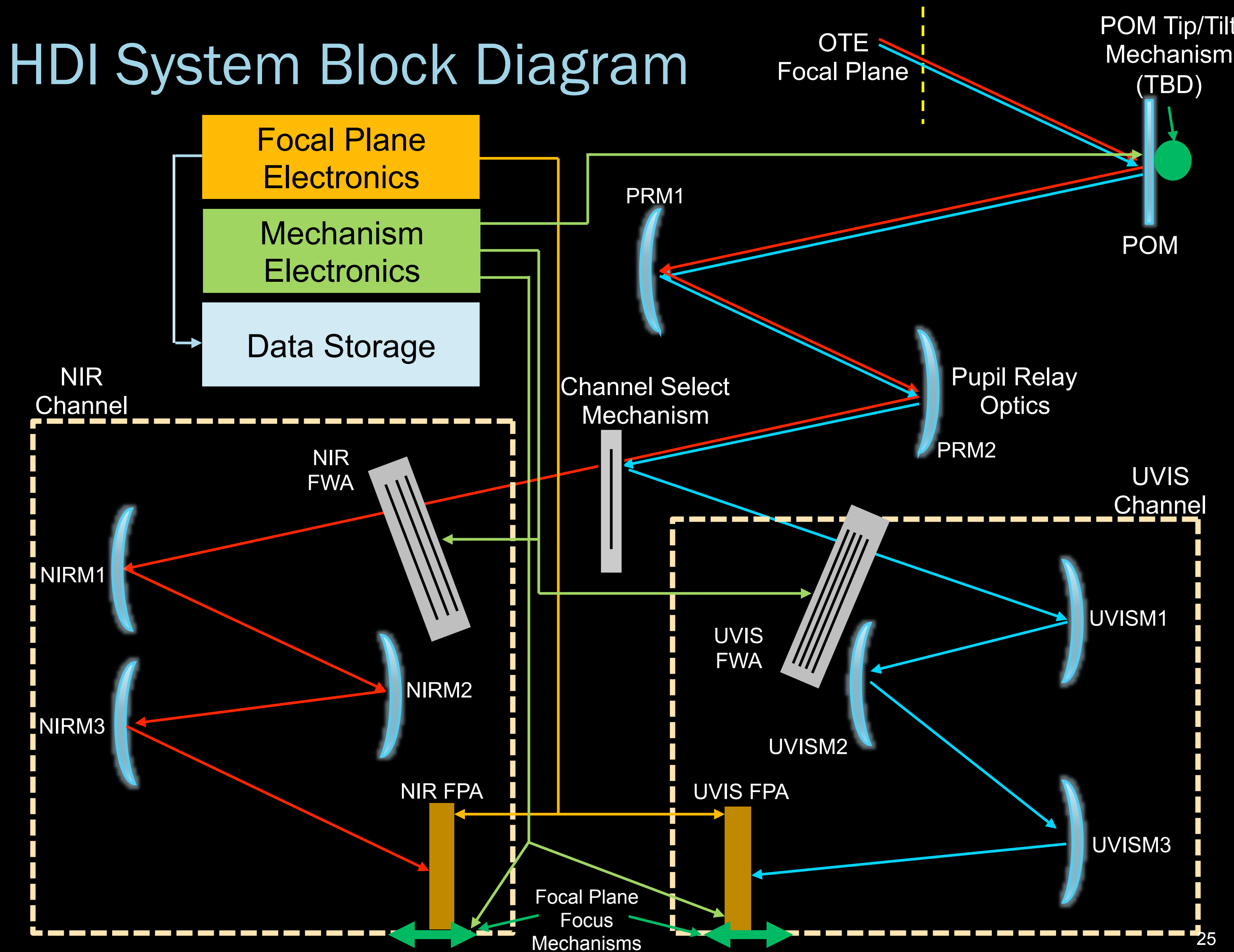
- High-Precision Astrometry (for measuring exoplanet mass)
  - Astrometric precision of < 5×10^{-4} pixels
  - Requires a Pixel Calibration System to calibrate pixel geometry

- Fine-guiding
  - HDI is the primary fine-guidance sensor for the LUVOIR observatory
  - Similar to WFIRST operation
    - Requires ability to define regions of focal plane with faster readout
    - Should have capability in both UV/Vis and NIR channels

- Image-based Wavefront Sensing (i.e. phase retrieval) for telescope commissioning and maintenance
  - Similar to role played by NIRCam on JWST
  - Requires inclusion of:
    - Weak-lenses for generating defocused images
    - Dispersed Hartmann Sensor (DHS) gratings for coarse piston sensing
    - Pupil Imaging Lens (PIL) subsystem

Via M. Bolcar & HDI team

HDI



Via M. Bolcar & HDI team

LUMOS

LUMOS Technical Overview (1/2)

- Two-channels with two separate fields-of-view:
  - 1.6 x 3 arcmin multi-object, multi-resolution FUV and NUV spectrograph
  - 2 x 2 arcmin FUV imager

- Nominal instrument bandpass is 100 nm – 400 nm
  - “FUV” ~ 100 – 200 nm
  - “NUV” ~ 200 – 400 nm

- Multi-object spectrograph (MOS) uses microshutter array at OTE focal plane to slice image and 6 fixed gratings to select resolution & detector
  - 3 medium resolution (R~45,000) FUV gratings (G120M, G150M, G180M)
  - 1 low resolution (R~8,000) FUV grating (G155L)
  - 1 ultra-low resolution (R~500) FUV grating (G145LL)
  - 1 medium-resolution (R~40,000) NUV grating (G300M)

Via M. Bolcar & LUMOS team

LUMOS

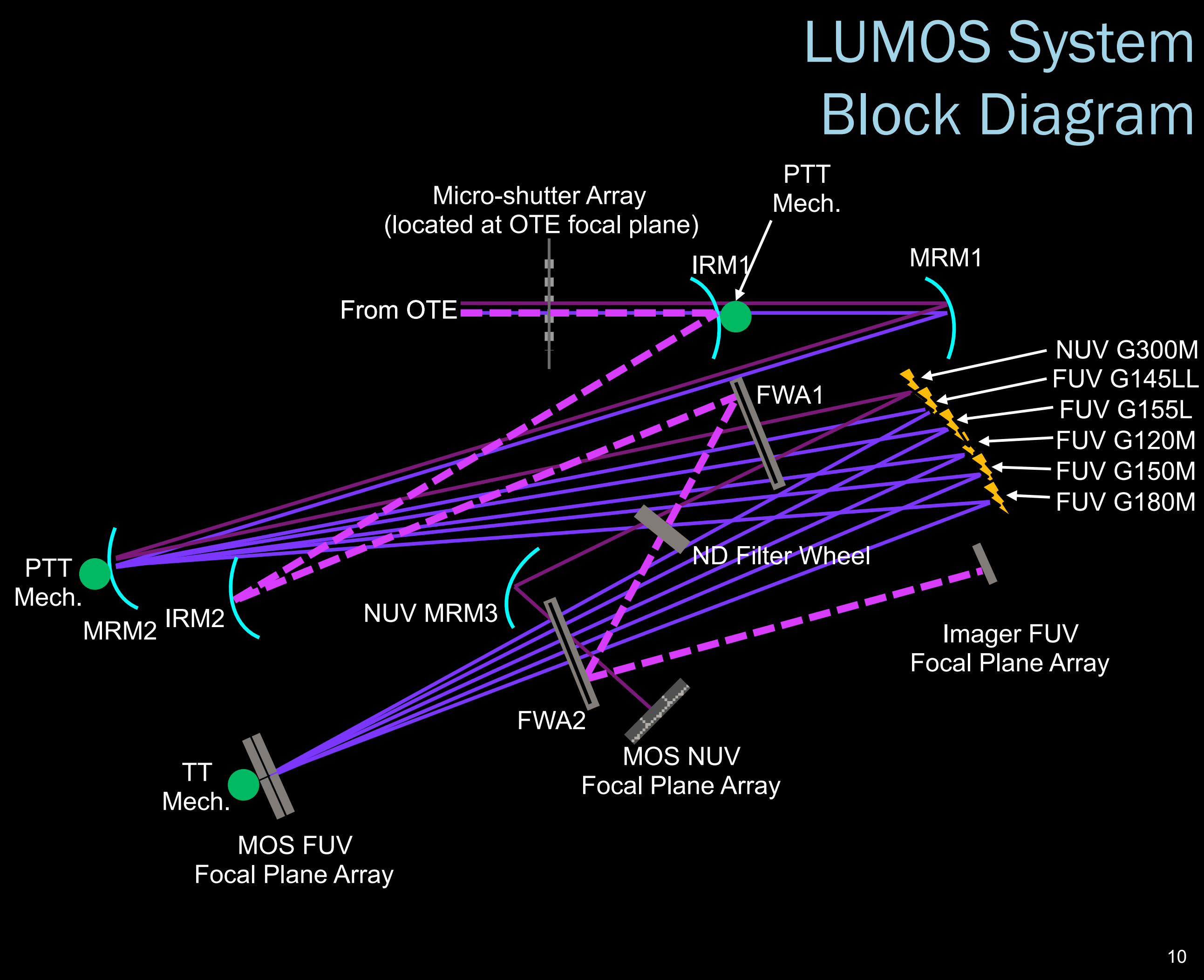
LUMOS Technical Overview (2/2)

- Imaging channel uses two reflective filters in series to achieve high out-of-band rejection
  - 7 “slots” in each wheel
    - 5 narrowband reflective filters
    - 1 broadband reflective filter (i.e. effectively wide-open bandpass)
    - 1 “cross-over” mirror (see below)
  - Both wheels contain identical filters
    - Identical filters are used in series to enhance out-of-band rejection
  - Additional transmissive filter-wheel at pupil plane with ND filters for bright-object imaging

- Special “cross-over” mode:
  - Images the micro-shutter array in the MOS channel to the detector in the imaging channel
  - Allows for target alignment in the micro-shutters, as well as monitoring shutter health

Via M. Bolcar & LUMOS team

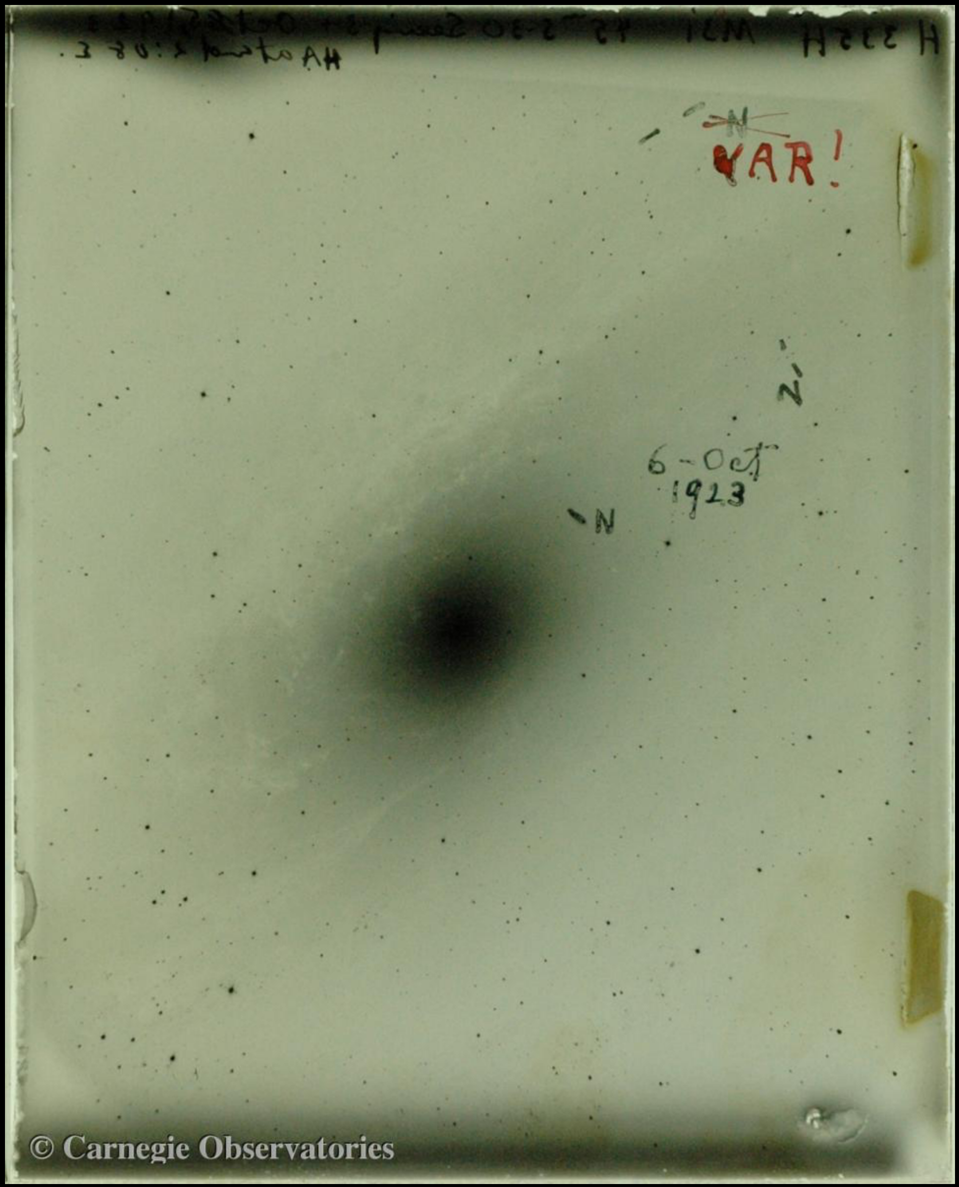
LUMOS



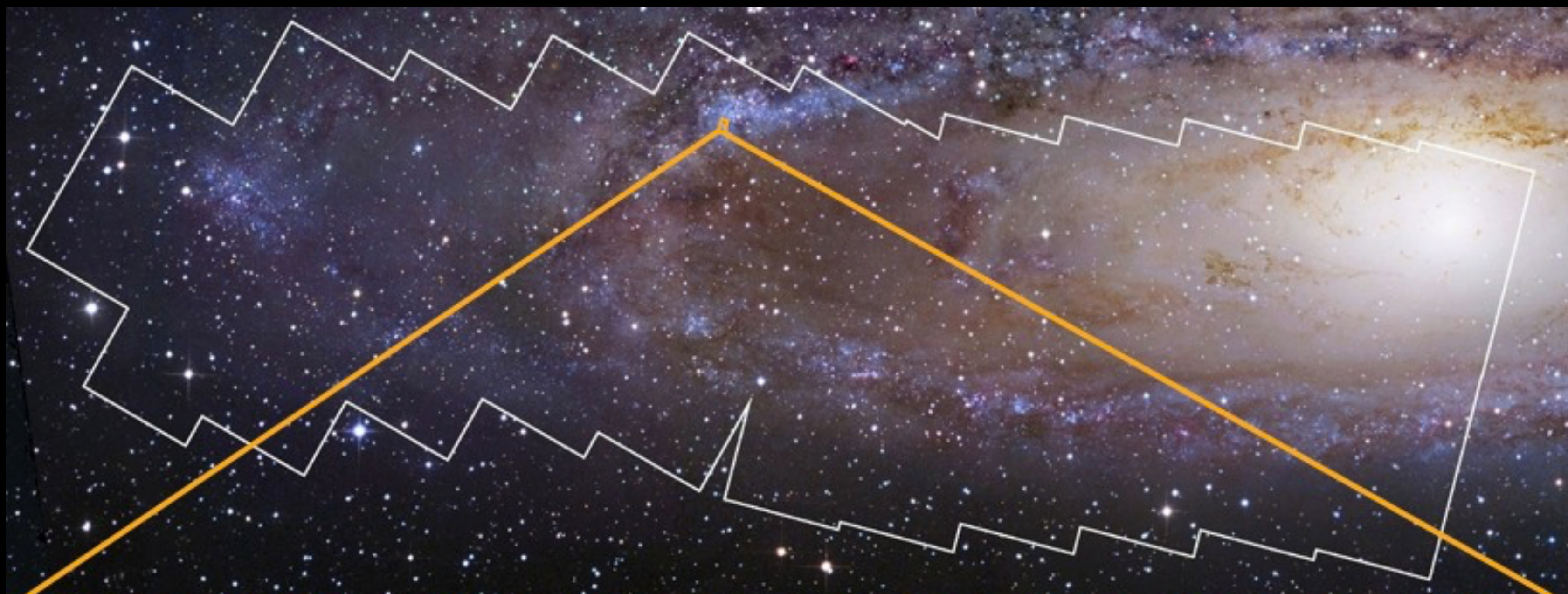
Via M. Bolcar & LUMOS team

GALAXIES WITH LUVOIR

THE POWER OF APERTURE: OLD SCHOOL EDITION

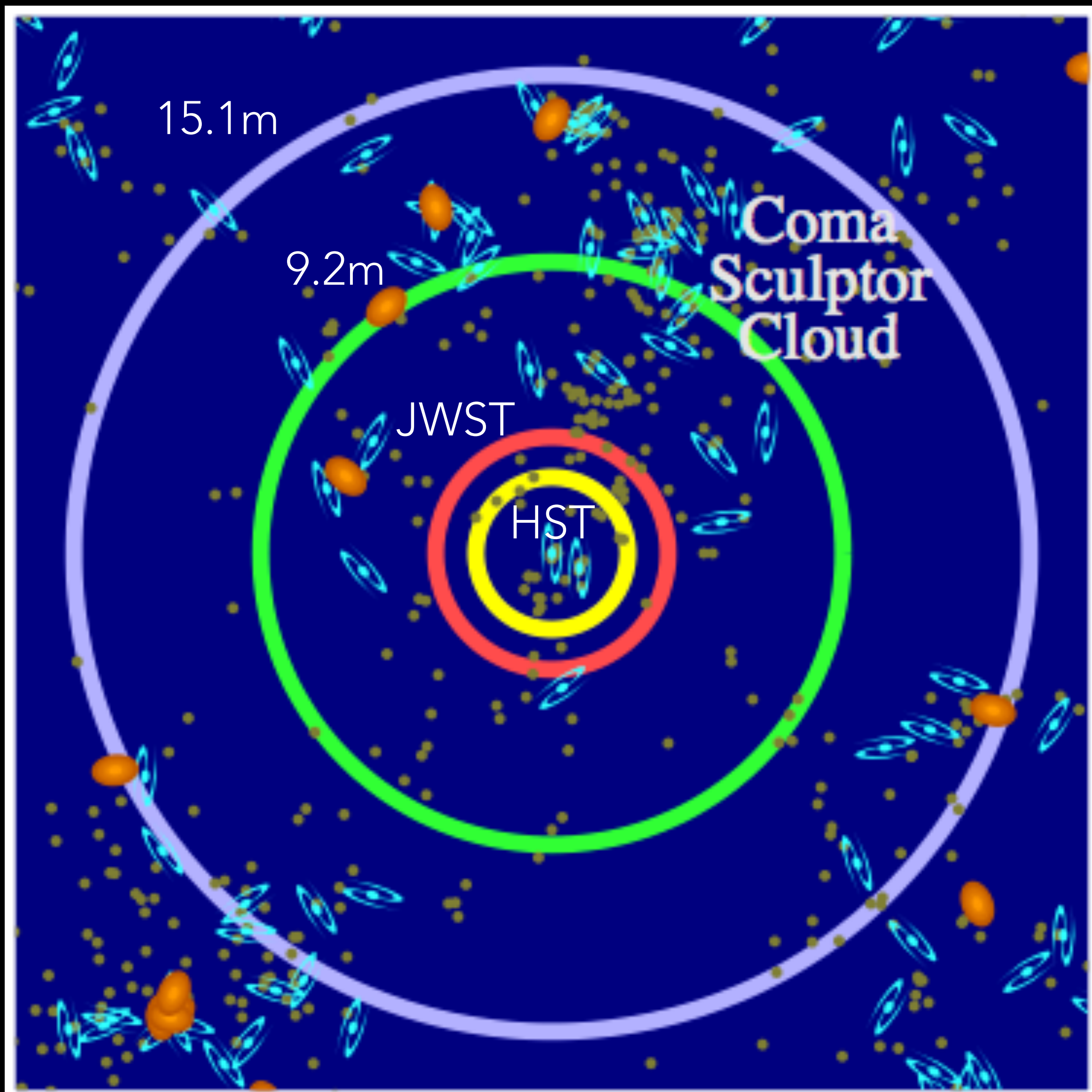


STAR FORMATION HISTORY

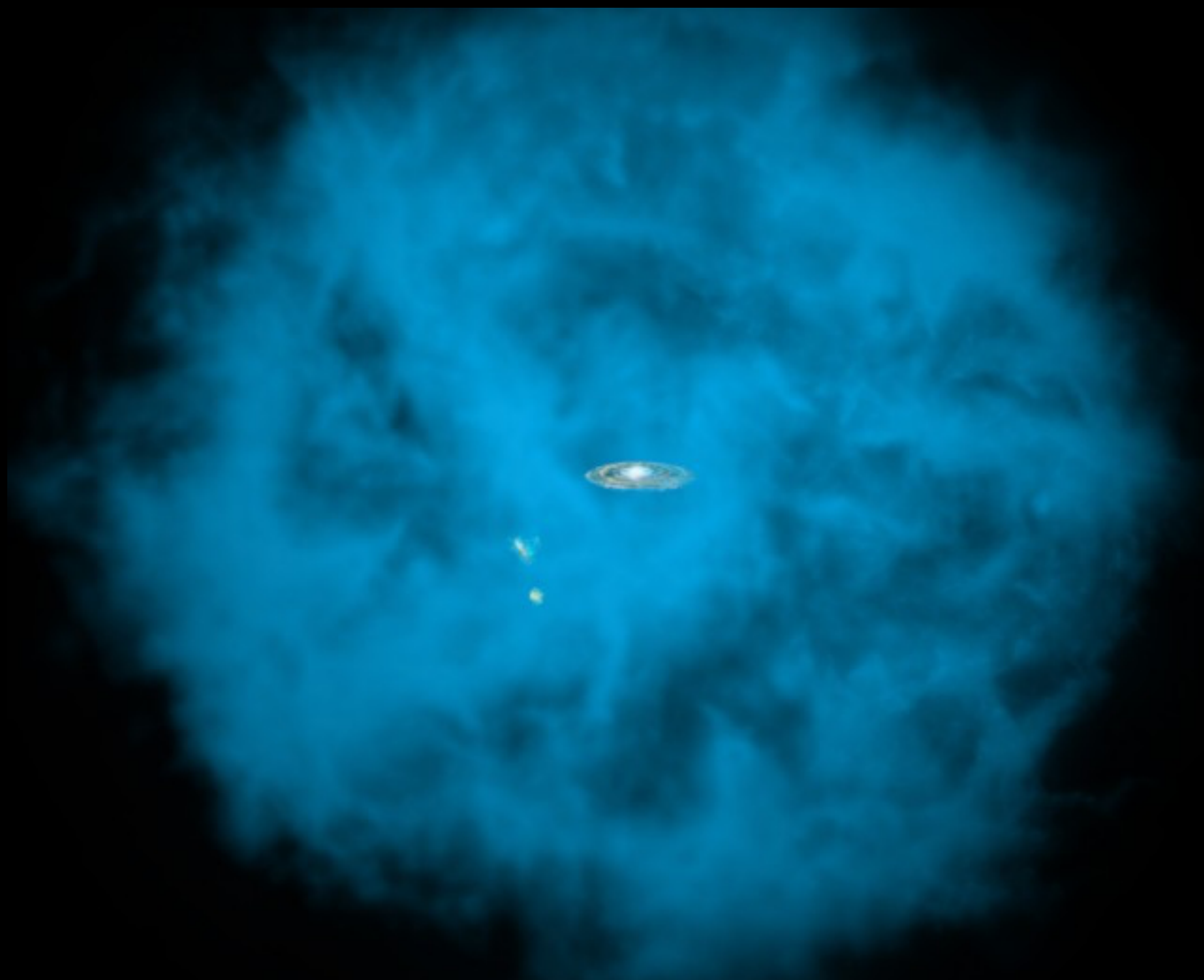


PHAT: J. Dalcanton et al.

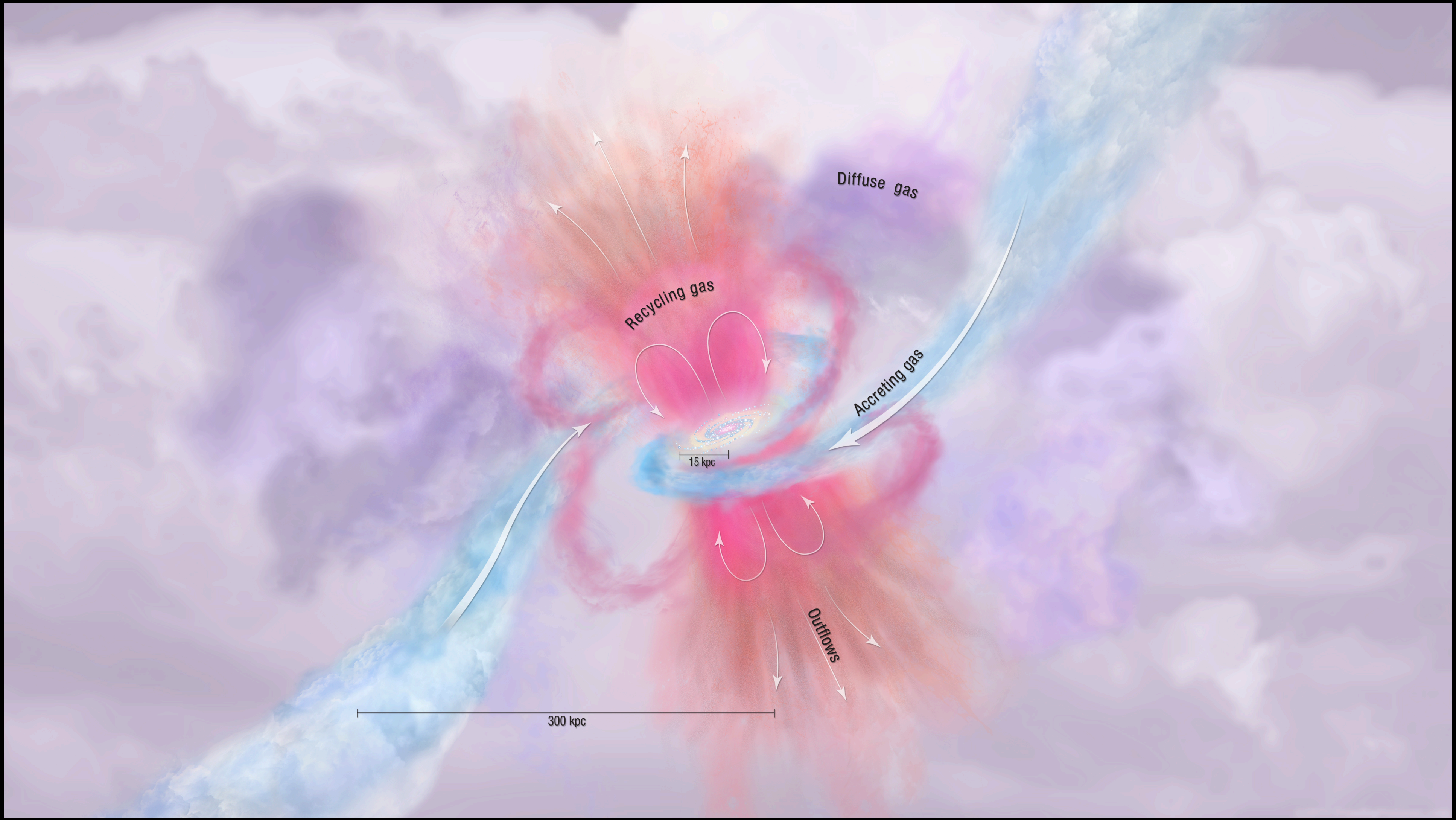
STAR FORMATION HISTORY



THE CGM

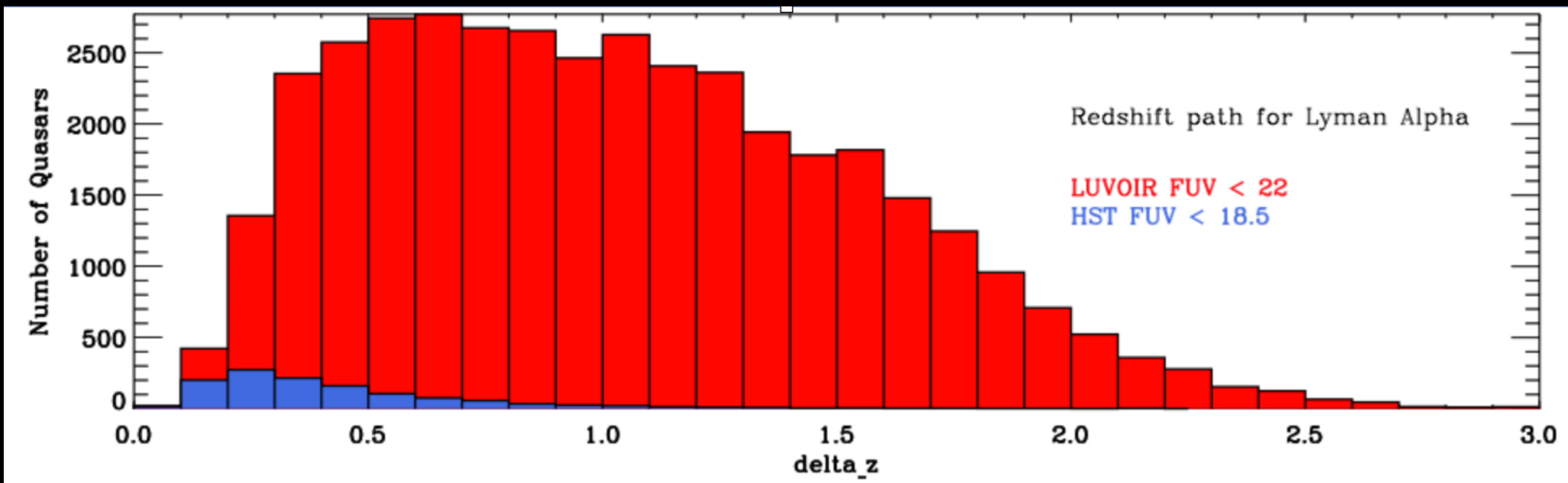


THE CGM

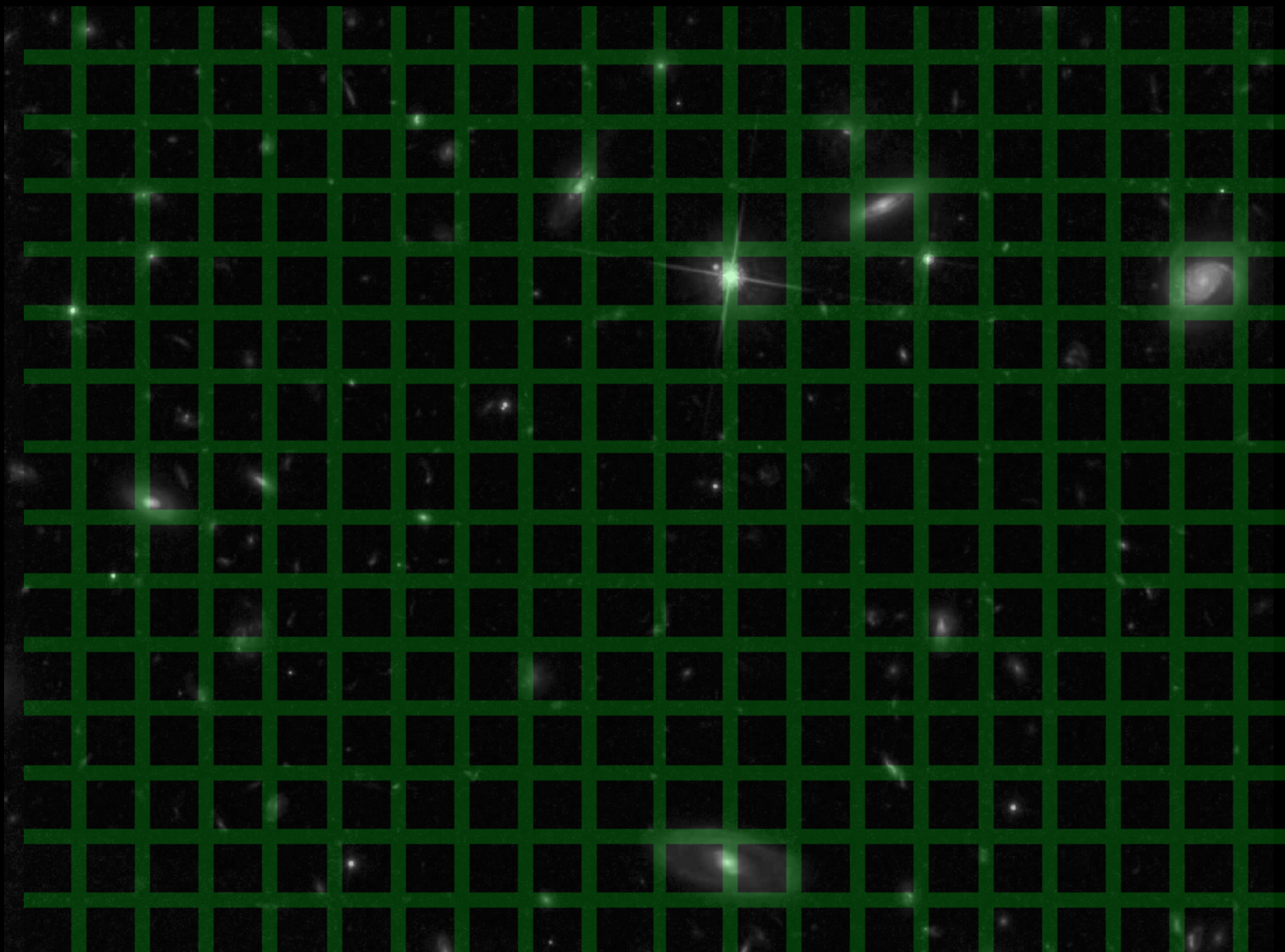


Courtesy: Tumlinson, Peeples, Werk

TRADITIONAL CGM METHODS



WHY DO ONE WHEN YOU CAN DO 100?



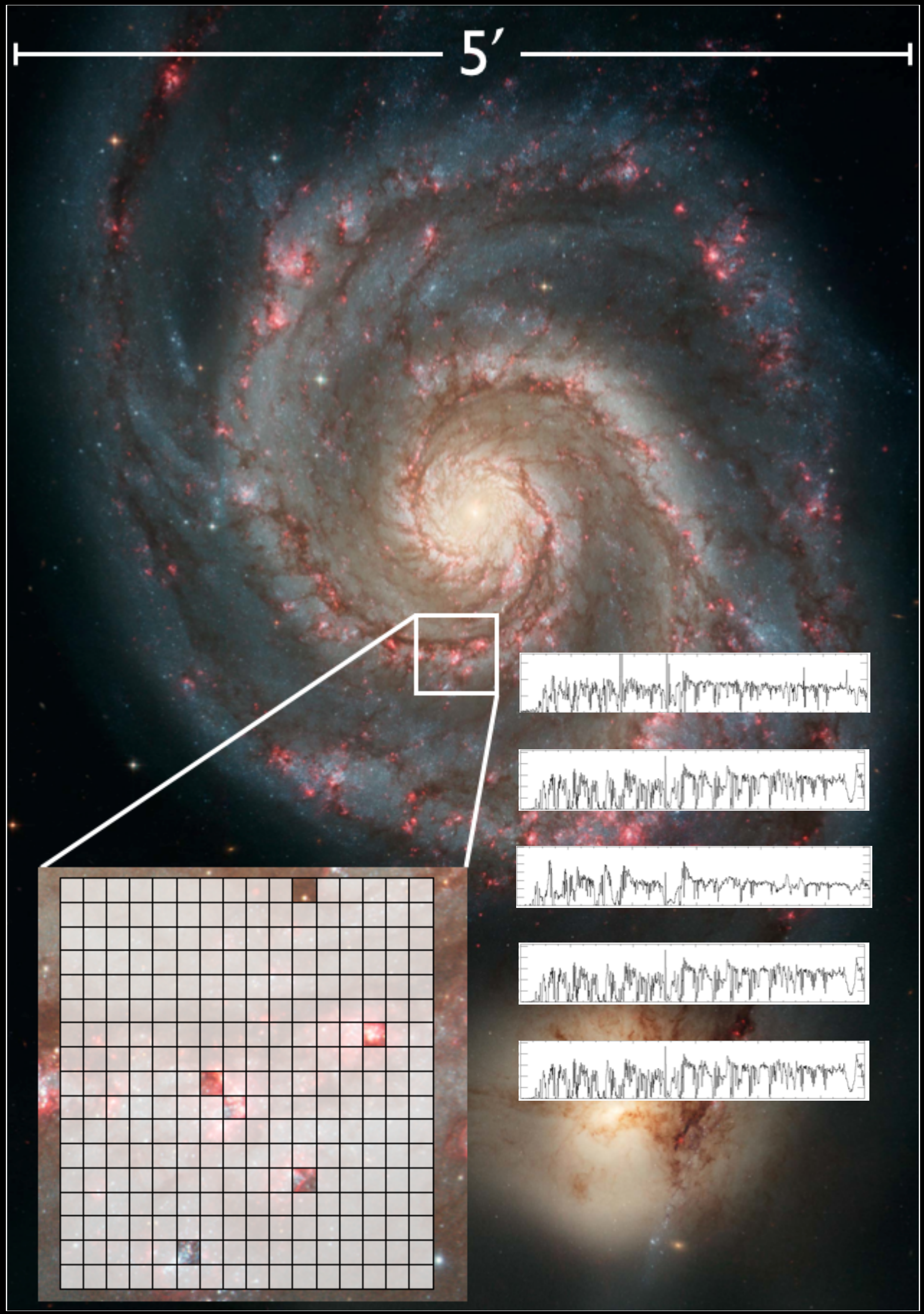
LUMOS:

25th mag galaxy at 5 σ in 1 hour.

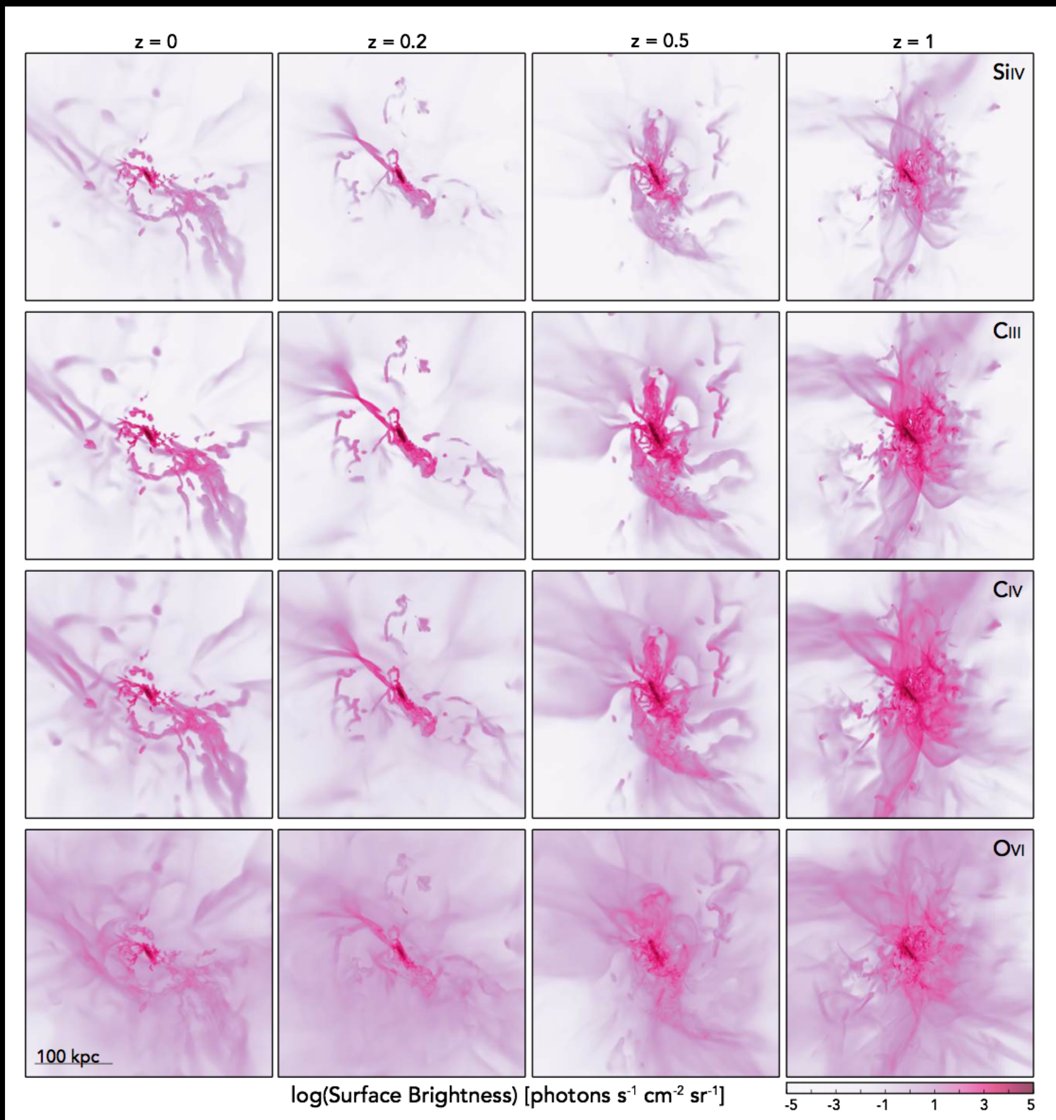
There are ~10,000 such galaxies per square degree

LUMOS MOS

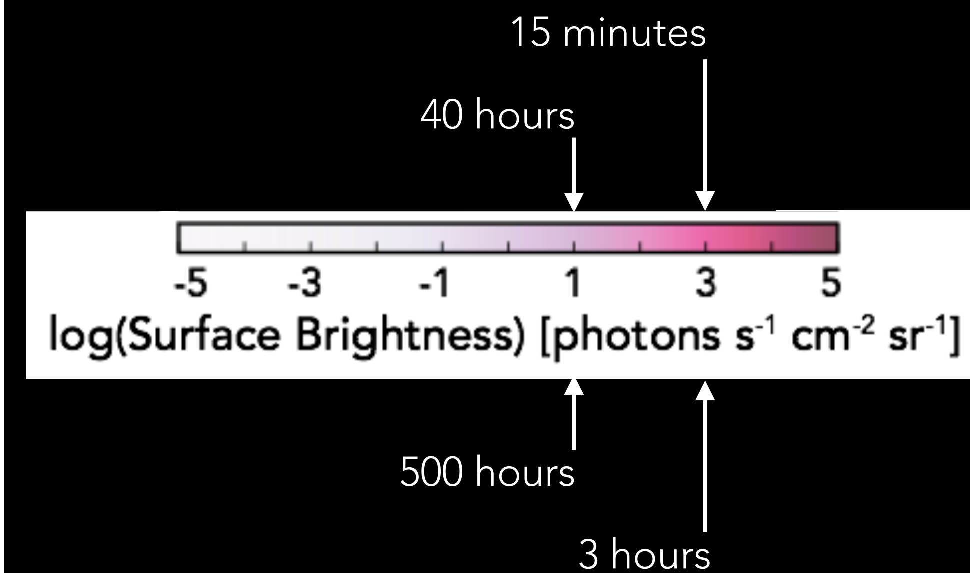
- Map young stellar clusters
- Use them as the background sources to probe inflows and outflows into the galaxy ISM/CGM/IGM



GAS, AND GALAXIES, AND LIGHT, OH MY



10 meter telescope



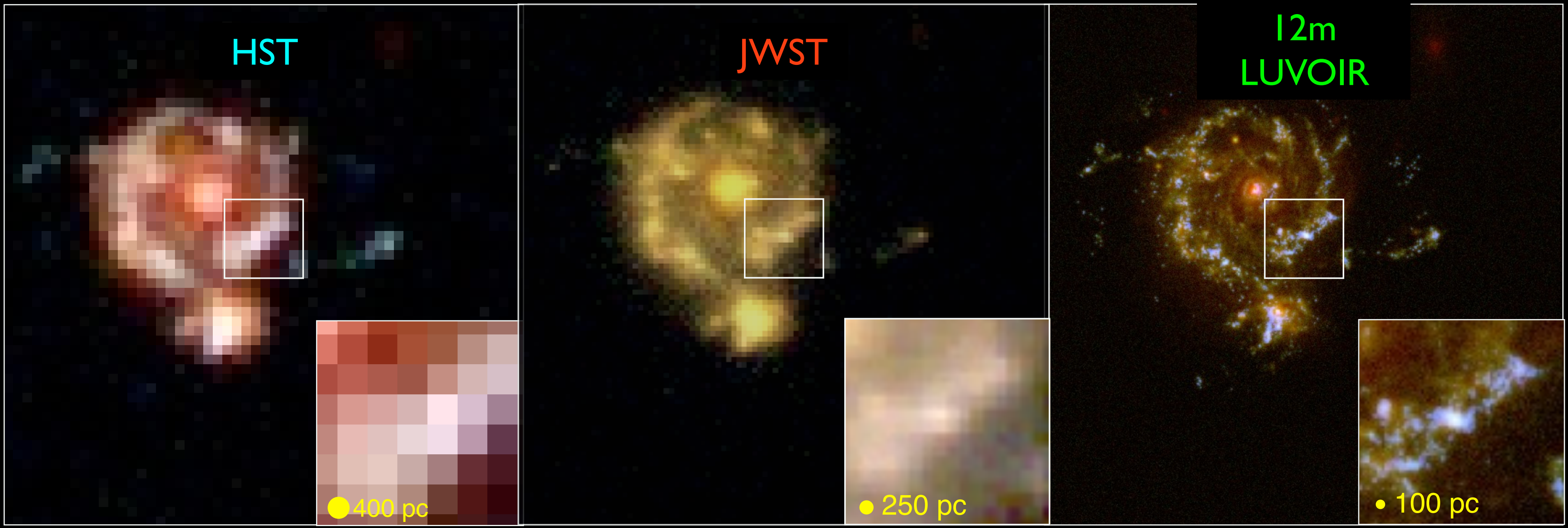
4 meter telescope

via David Schiminovich

GALAXY STRUCTURE AND EVOLUTION ACROSS COSMIC TIME

How Did the Milky Way Form from its Earliest Seeds?

Epoch	Resolution
z = 1 - 4	30-100 pc

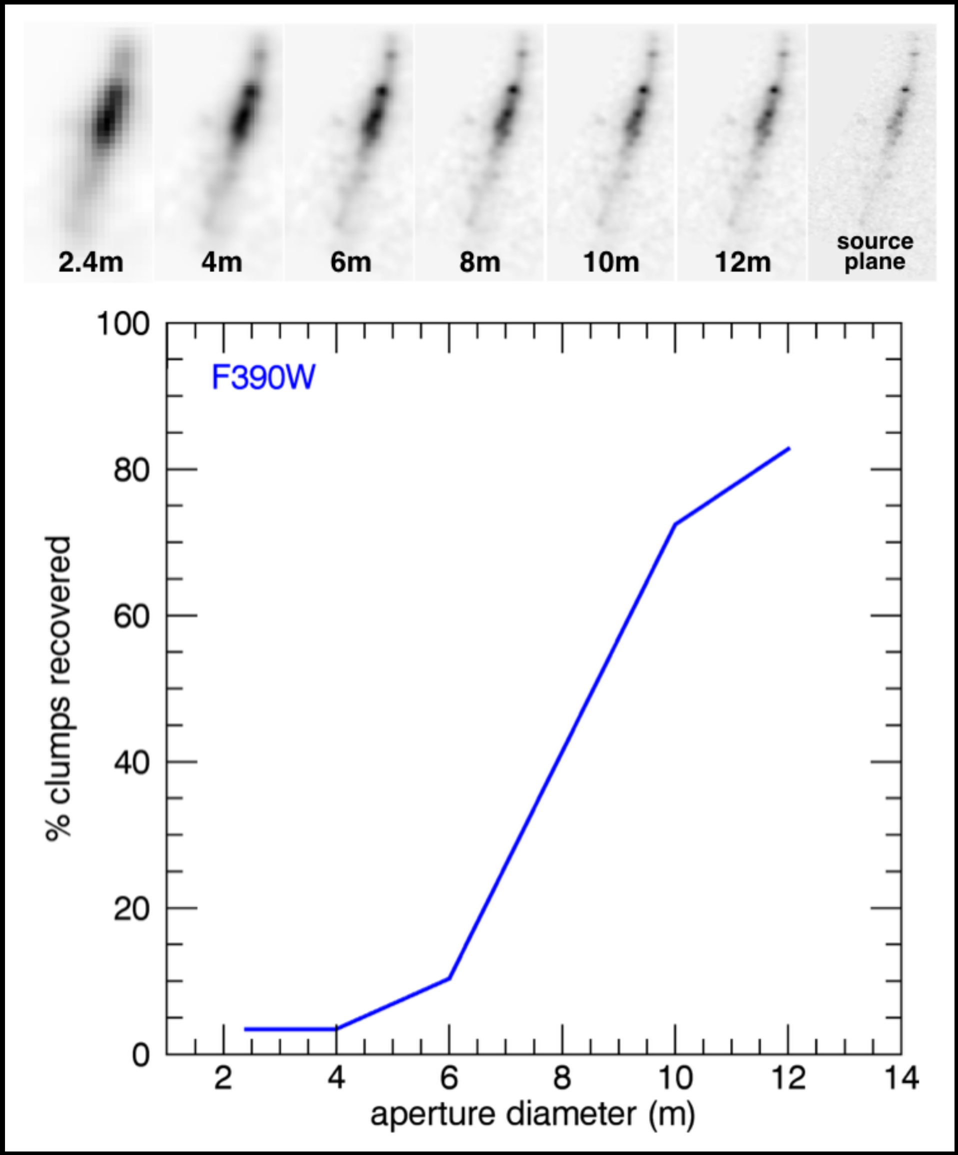


With <u>unique 100 parsec resolution</u> in the optical at all redshifts, LUVOIR can resolve ALL the building blocks of galaxies: individual star forming regions and dwarf satellites, including progenitors of the present-day dwarf spheroidals.

These high-resolution images will complement ELT and ALMA spectroscopy of the galaxies and their molecular gas.

slide courtesy J. Tumlinson

A REMINDER ABOUT SPATIAL SCALES



Lensed galaxies with HST

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normal galaxies with LUVOIR

via Kate Whitaker and Jane Rigby

GALAXIES, REIONIZATION, AND THE LUMINOSITY FUNCTION

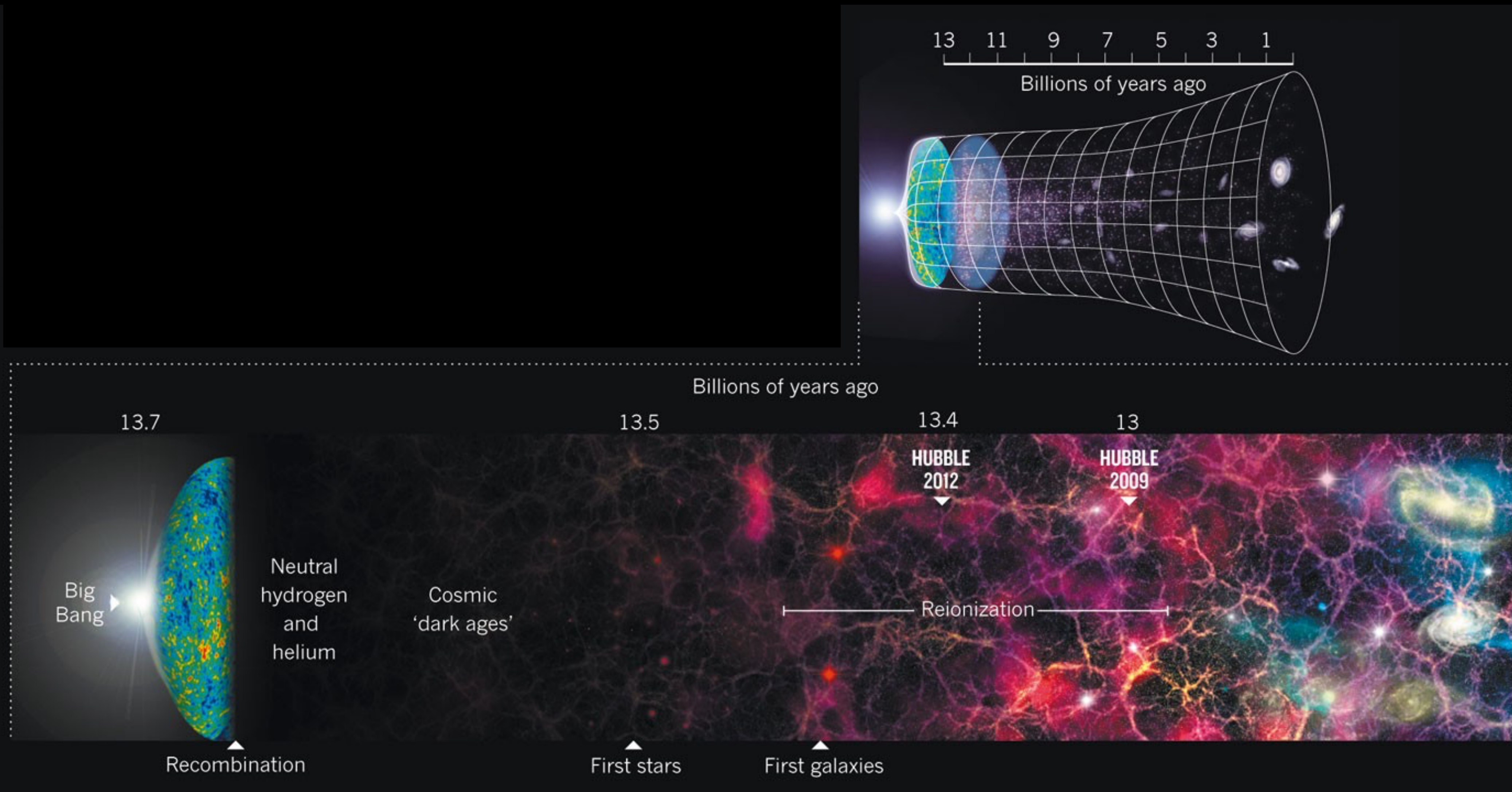
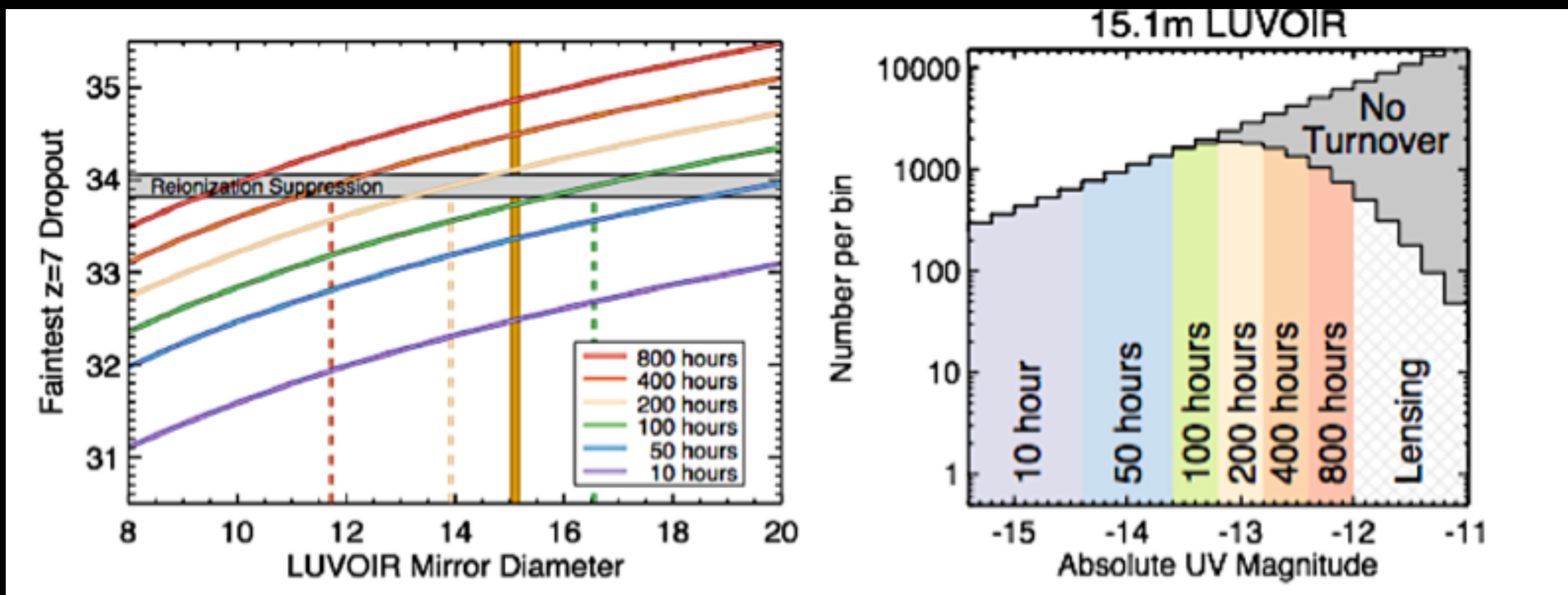


Illustration: Nik Spencer

GALAXIES AND REIONIZATION



S. Finkelstein

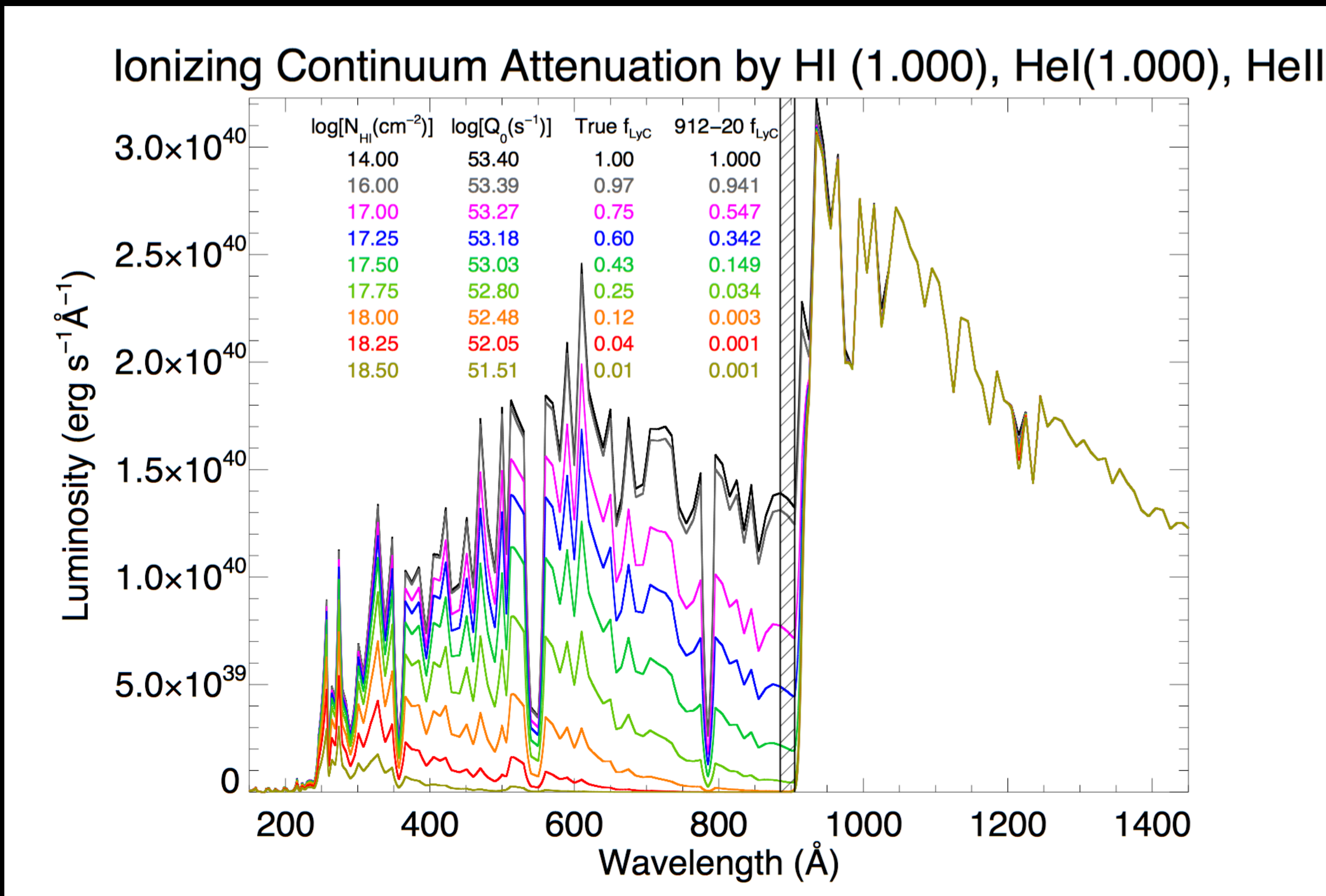
GALAXIES AND REIONIZATION

Exposure times to reach depths of 33.9(J,H) & 34.2 (i)

APERTURE/ FILTER EXPOSURE TIME	4M	6.5M	9.2M	15.1M
I	3.35E+08	4.88E+07	1.25E+07	1.66E+06
J	8.10E+07	1.16E+07	2.90E+06	4.00E+05
H	7.28E+07	1.06E+07	2.57E+06	3.62E+05
TOTAL (HOURS)	1.36E+05 (15.5 YEARS)	1.97E+04 (2.25 YEARS)	4.99E+03 (0.57 YEARS)	6.73E+02 (4 WEEKS)

S. Finkelstein

GALAXIES AND REIONIZATION



Goal: sensitivity to f_esc = 0.01 for thousands of objects

Needs: LUMOS & 12+ meter (9 meter means reduced survey size/weaker sensitivity/longer program)

via Stephen McCandliss

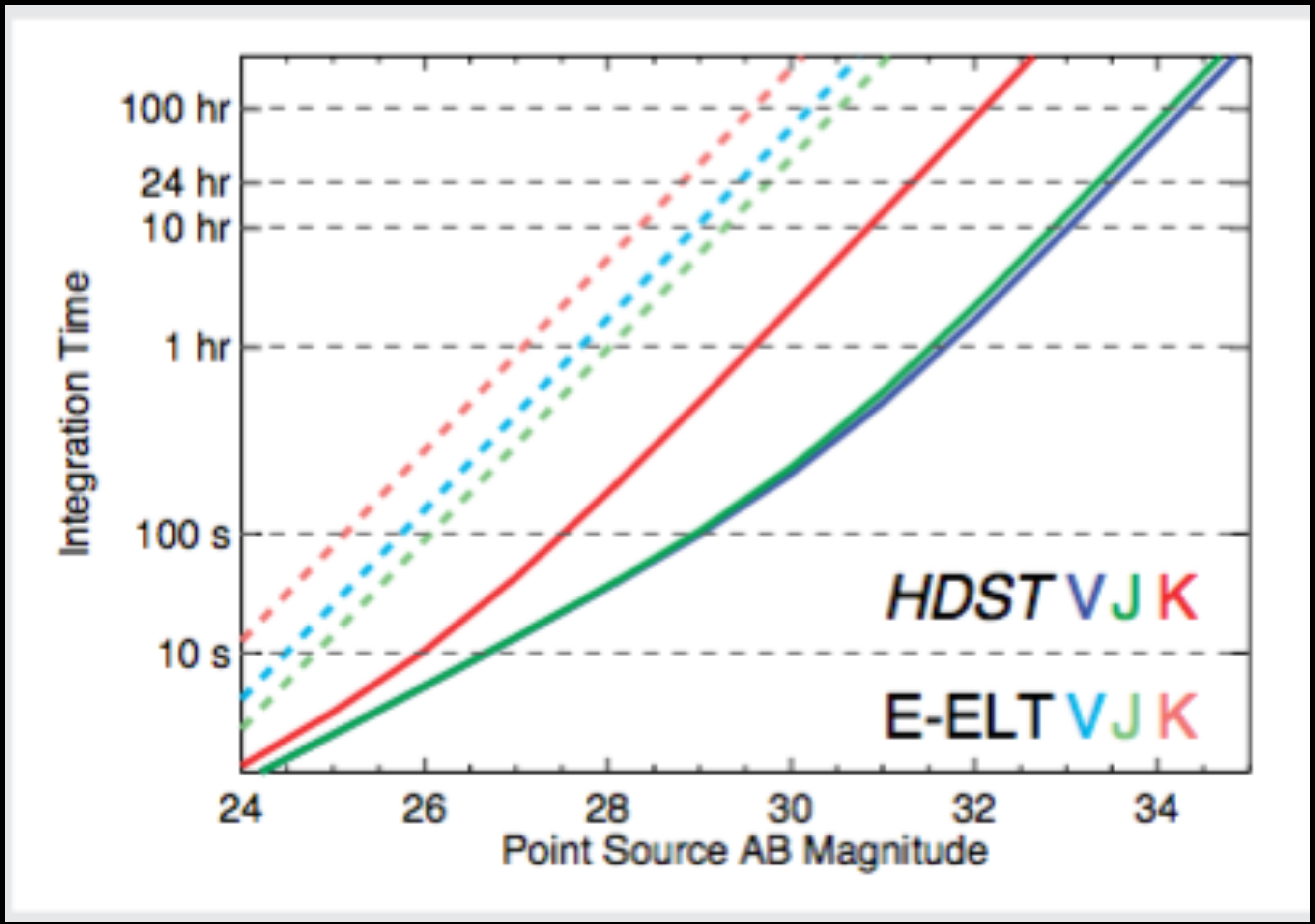
THE GALAXY ECOSYSTEM

HST Frontier Fields Parallels

REMEMBER THOSE COOL EXOPLANET OBSERVATIONS?

- Deep parallels yield a total of ~1 year observing time
- Area on sky approaches 1 square degree
- See nearly *all* star forming galaxies and most star forming satellites
- Consider volume: total coming volume at z~2-3 is roughly the equivalent to the volume of the entire SDSS.

YEAH, BUT THE 30-METERS WILL DO THIS ALL



from the HDST report

"MISCELLANY"

- ~1pc resolution for thousands of nearby galaxies: age-dating clusters to explore how they formed with their hosts
- Ultra-precise astrometry gives ~1 m/s accuracy to 100 pc, ~10 km/s to anywhere in the Local Group: stellar dynamics reveals the mass structure

BIG QUESTIONS

- How are galaxies assembled, and how do they fuel their stars?
  - Deep imaging at small scales reveals even the faintest clumps at high z
  - Luminosity function to capture nearly all galaxies
  - CGM maps and down the barrel spectroscopy show the gas in motion

BIG QUESTIONS

- How are galaxies assembled, and how do they fuel their stars?
- How does the Hubble sequence emerge?
  - Small scale imaging reveals the disk->bulge transition
  - AGN outflow observations + CGM maps catch quenching in the act

BIG QUESTIONS

- How are galaxies assembled, and how do they fuel their stars?
- How does the Hubble sequence emerge?
- Do galaxies reionize the universe?
    - Must combine UV at $z<2$ with Optical/NIR at $z>6$