21st Century astronomers should be uniquely positioned to study “*the evolution of the universe in order to relate causally the physical conditions during the Big Bang to the development of RNA and DNA*”

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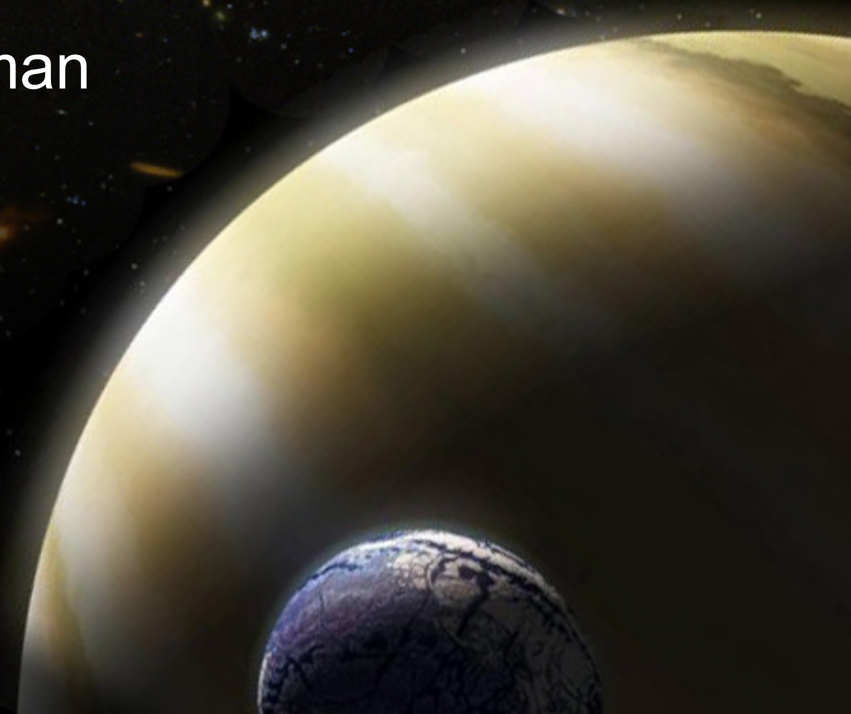
Riccardo Giacconi, 1997

Future High-Angular UV-Optical Imaging Capability From Space

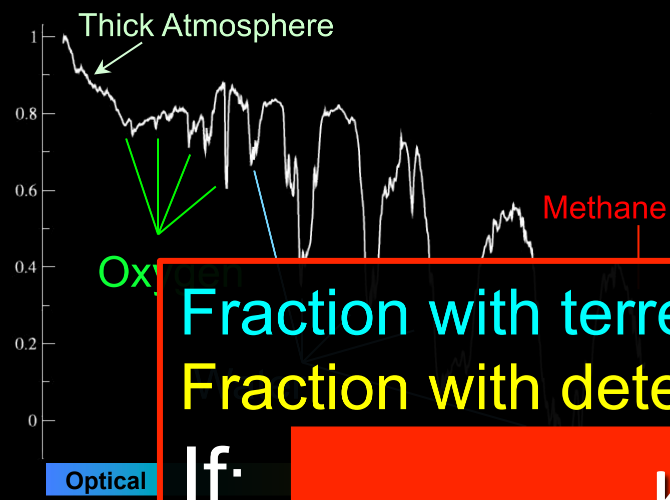
Marc Postman

“The most important experiment in modern biology is the search for extra-terrestrial life.”

E. O. Wilson
Evolutionary Biologist
June 2, 2012



“Is there another Earth out there?”



Fraction with terrestrial planets = η_{Earth}

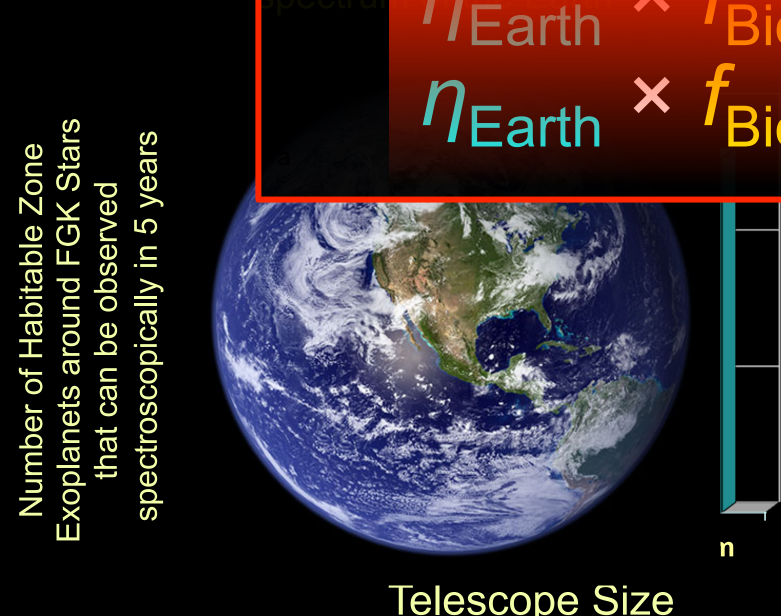
Fraction with detectable biosignature = f_{Bio}

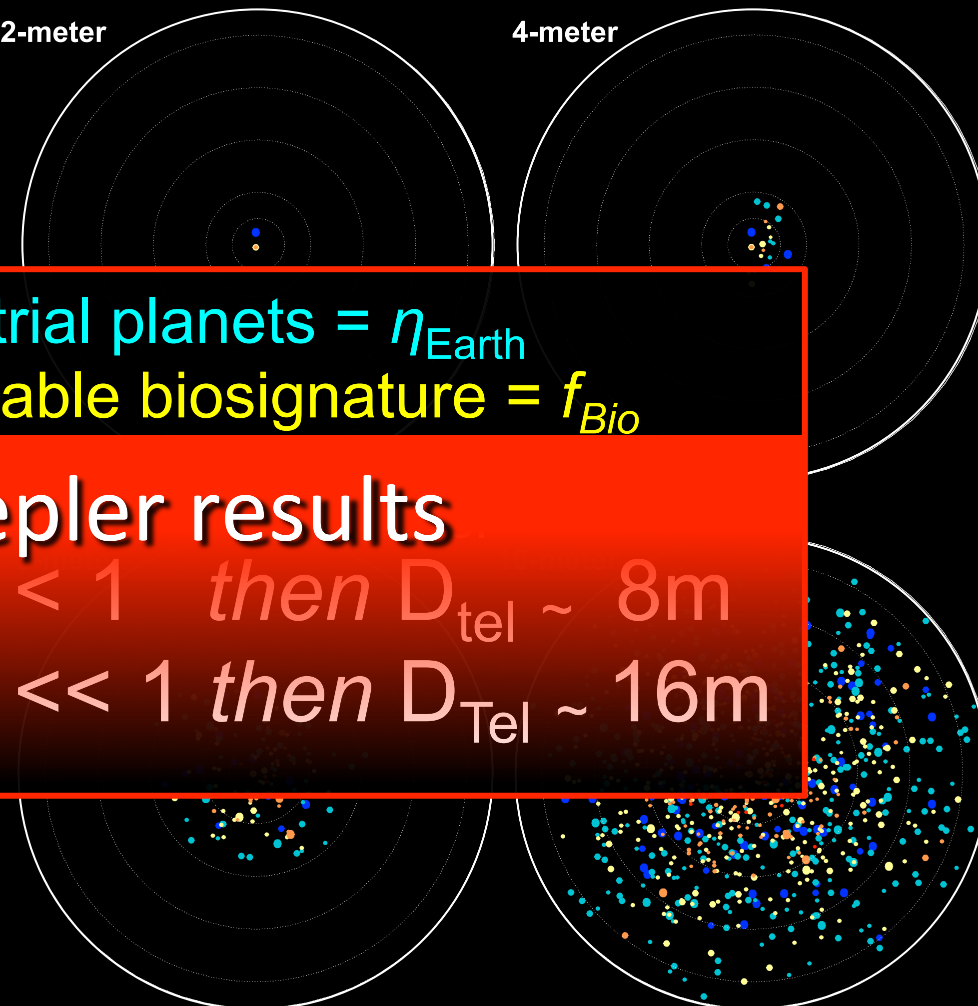
If:

Kepler results

$\eta_{Earth} \times f_{Bio} < 1$ *then* $D_{tel} \sim 8m$

$\eta_{Earth} \times f_{Bio} << 1$ *then* $D_{Tel} \sim 16m$

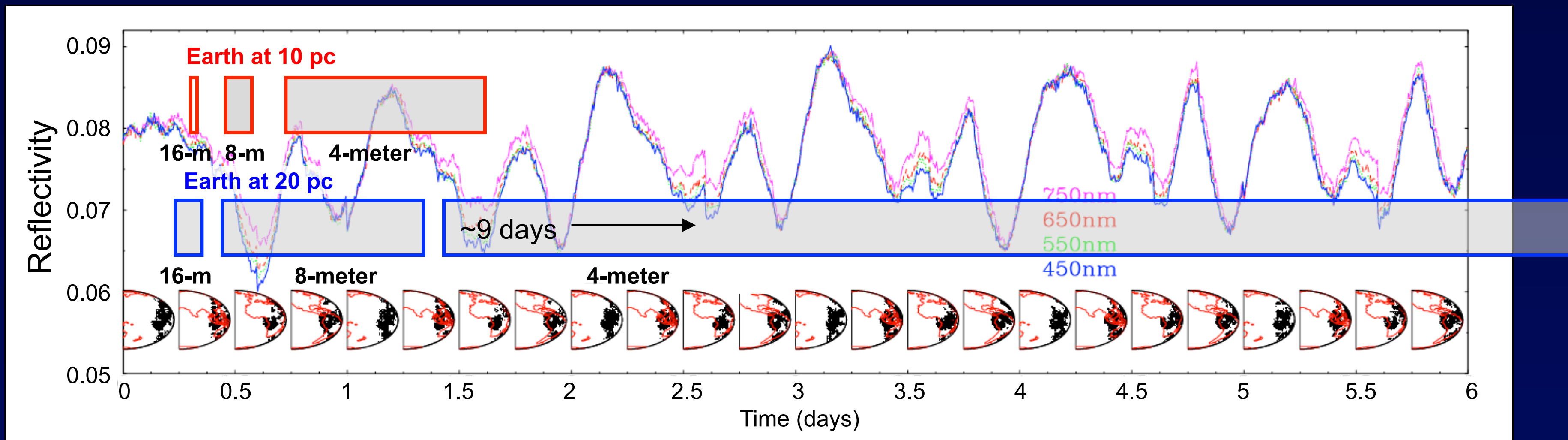




Above: Distribution of all FGK stars within 45 pc of the Sun where a R=70 spectrum of an Earth-twin could be acquired in <500 ksec *shown as a function of telescope aperture*.

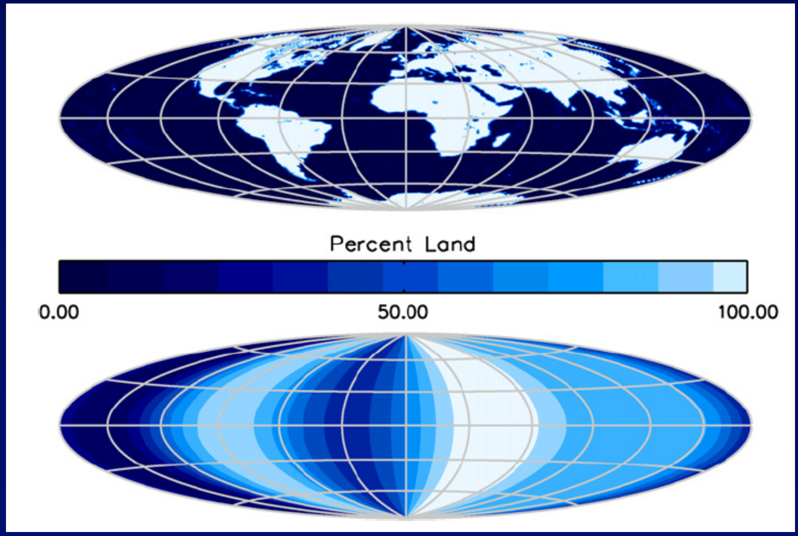
Detecting Diurnal Photometric Variability in Exoplanets

Ford et al. 2003: Model of broadband photometric temporal variability of Earth



Require S/N ~ 20 (5% photometry) to detect ~20% temporal variations in reflectivity.

Reconstruction of Earth's land-sea ratio from disk-averaged time-resolved imaging with the EPOXI mission.

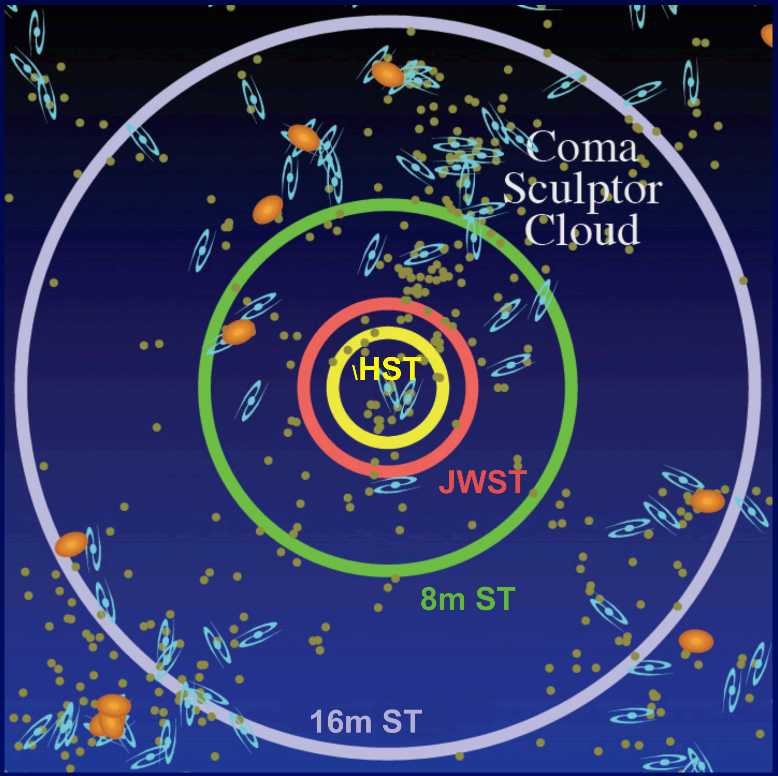


Establishing a Comprehensive Theory of Star and Galaxy Formation

Requires Sampling Resolved Stellar Populations and Probing Gas Kinematics Across a Broad Range of Galactic Environments

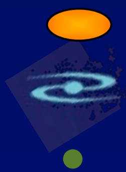
A Comprehensive Understanding of Star Formation Requires Sampling Resolved Stellar Populations in a Broad Range of Galactic Environments

Map of Galaxies within 12 Mpc of Our Galaxy



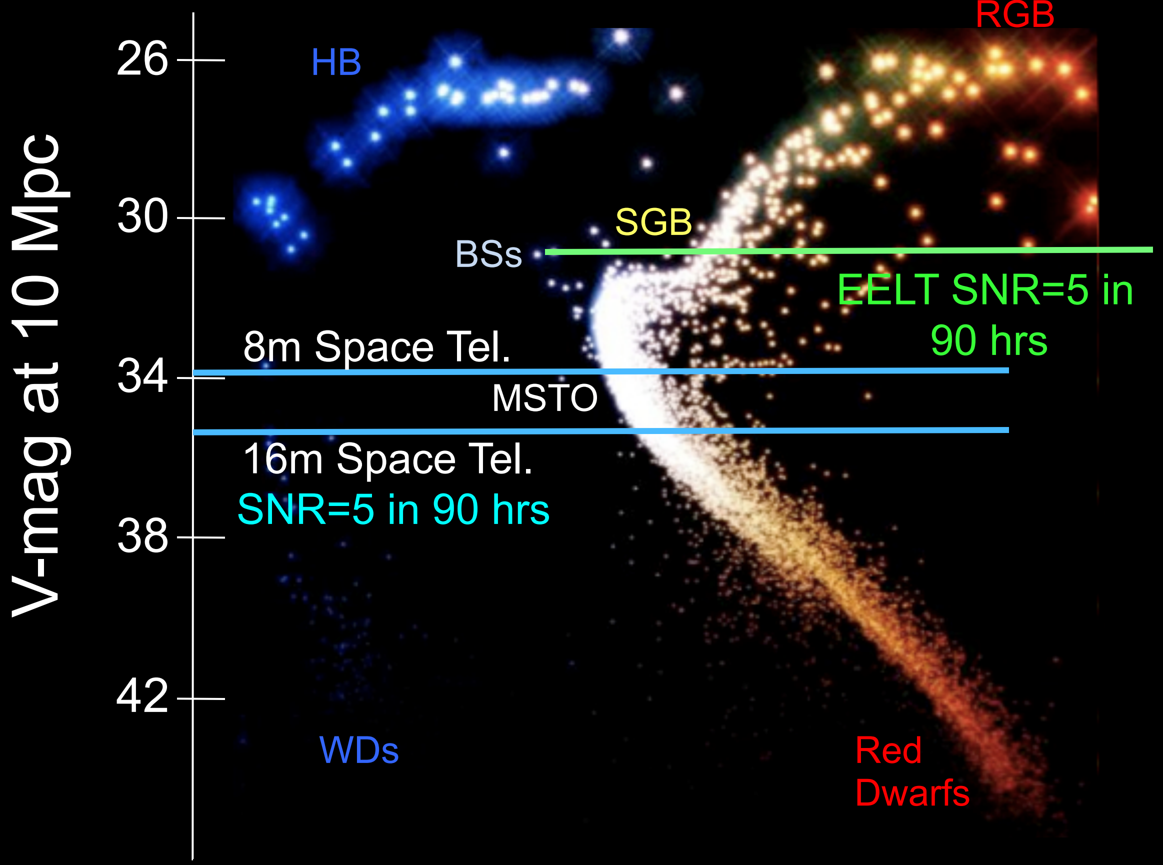
Circles in the figure to the left show the distance out to which a color of an individual ***solar type star*** can be measured (SNR=5) with a space telescope of indicated size (in 100 hours). This enables precise ages and star formation histories to be derived.

An 8-m telescope will be able to detect individual solar-type stars in the main sequence in 140 nearby galaxies, including the closest giant Elliptical galaxy – providing an accurate age estimate for their stellar populations. A 16-m can survey ~400 nearby galaxies, including ~50 large galaxies.



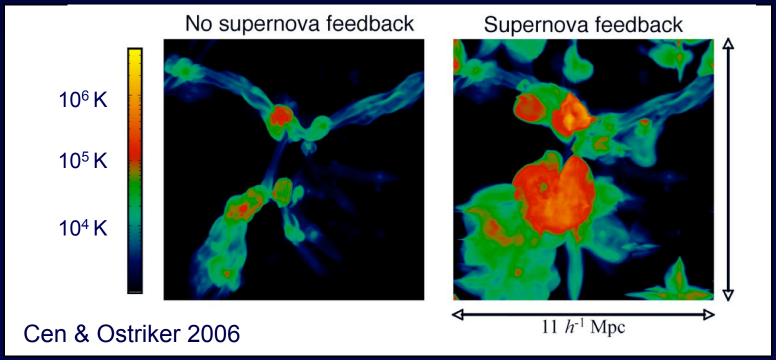
This will enable a major breakthrough in our understanding of how galaxies assemble their stars. No other planned facilities will have this capability.

Direct detection of the Main Sequence Turn-Off in Galaxies up to 10 Mpc Away



CMD image: J. Anderson
Flux scale: K. Olsen et al. 2009

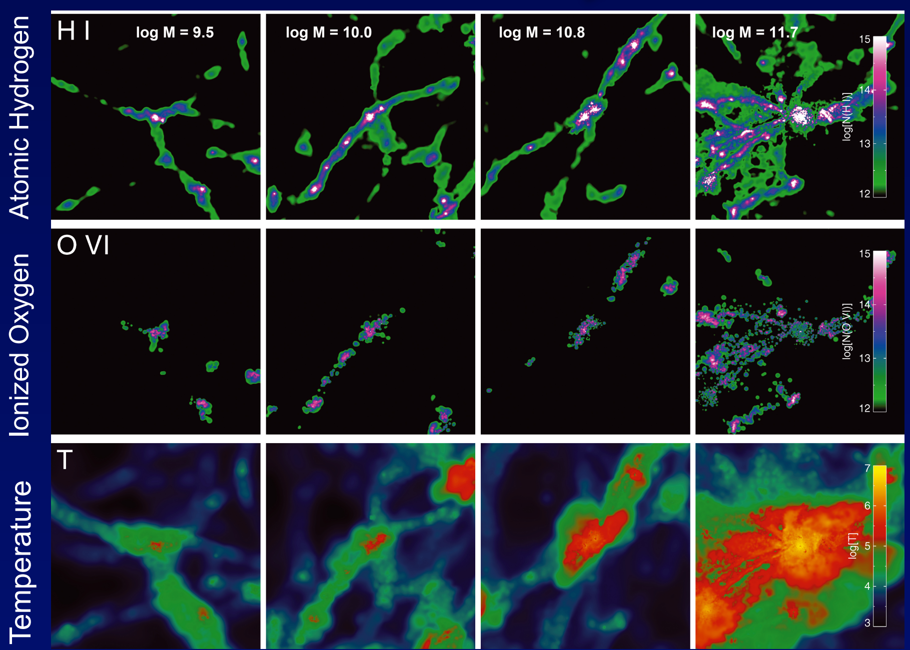
Understanding the Galaxy - IGM Interplay



Above: IGM gas temperature distribution for cosmological models with and without supernova feedback.

Below: Gas ionization and Temperature Distribution vs. Galaxy Mass

Lower Mass → Higher Mass



Oppenheimer et al. 2009

Most of the matter in the Universe is located in intergalactic space outside of galaxies.

The key questions are:

HOW IS INTERGALACTIC MATTER ASSEMBLED INTO GALAXIES?

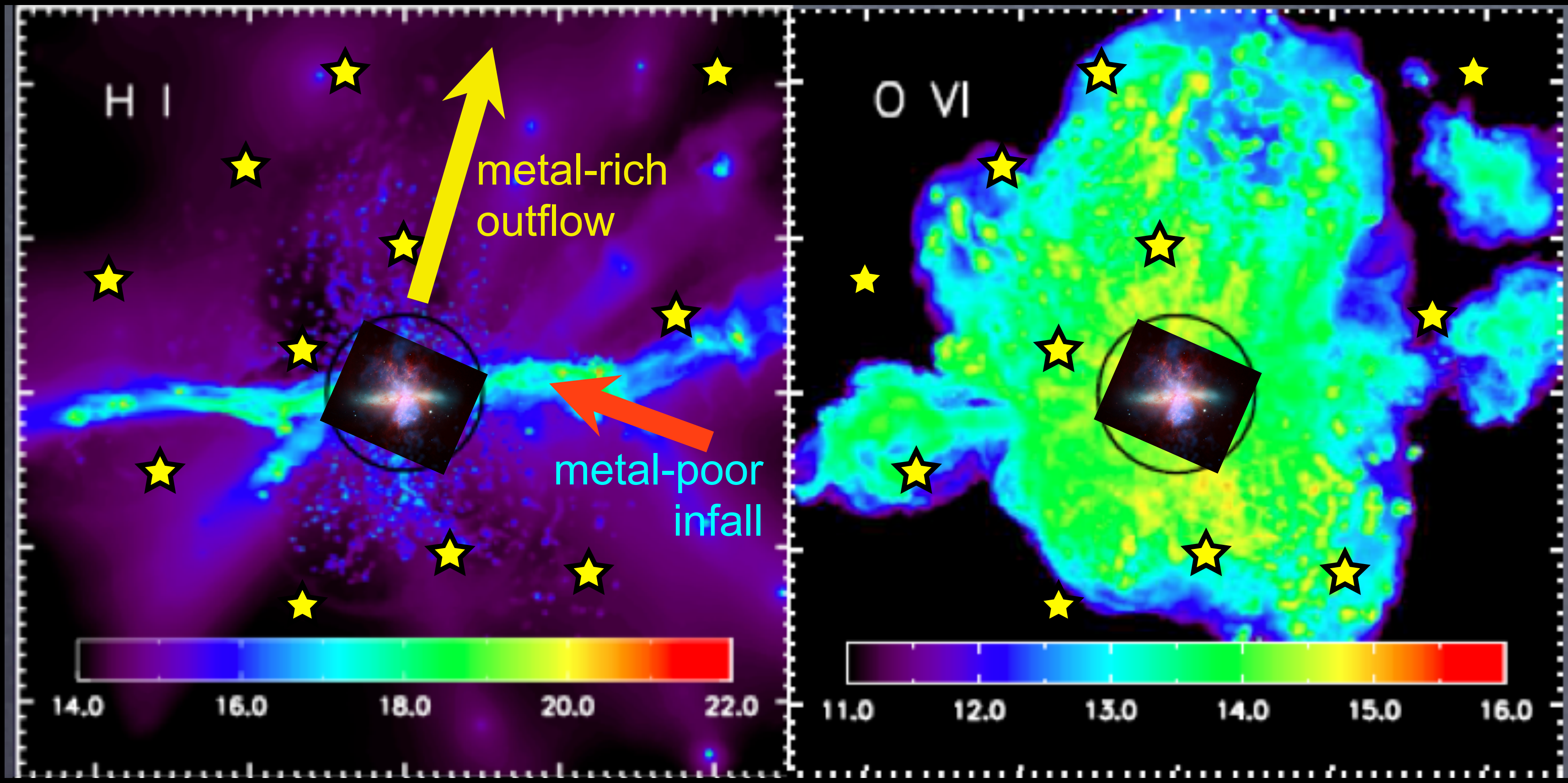
TO WHAT DEGREE DOES GALAXY FEEDBACK REGULATE AND ENRICH THE IGM?

WHERE AND WHEN DO THESE PROCESSES OCCUR AS A FUNCTION OF TIME?

Understanding the answers to these questions lies at the heart of understanding galactic evolution.

Halo gas dissection with M82

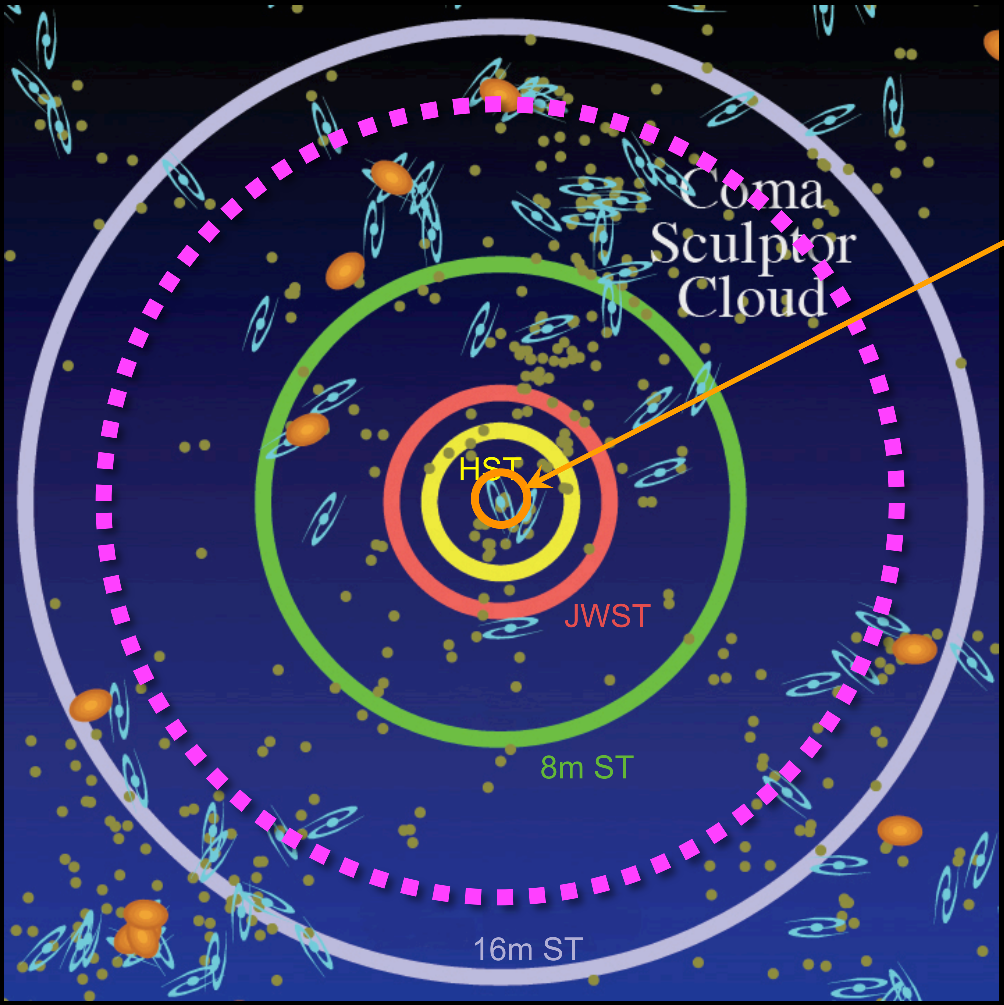
Simulations from Shen et al. 2012



Note: FUV from 900 - 1150 Å needed to obtain reliable HI column densities from Lyman series and O VI, the most sensitive probe of highly ionized gas.

Slide credit: J. Tumlinson

Synthesis of Approaches Enables Galaxy Evolution Studies in High-Definition



Map of Galaxies within 12 Mpc of Our Galaxy

HST/COS can in principle observe ~10 QSOs within 100 kpc of Andromeda. (small orange circle).

An 8-m can reach QSOs at m_{FUV} ~ 22, where there are ~ 10 / deg^2.

At this sky density, multiple probes of individual fully-resolved nearby galaxies becomes possible.

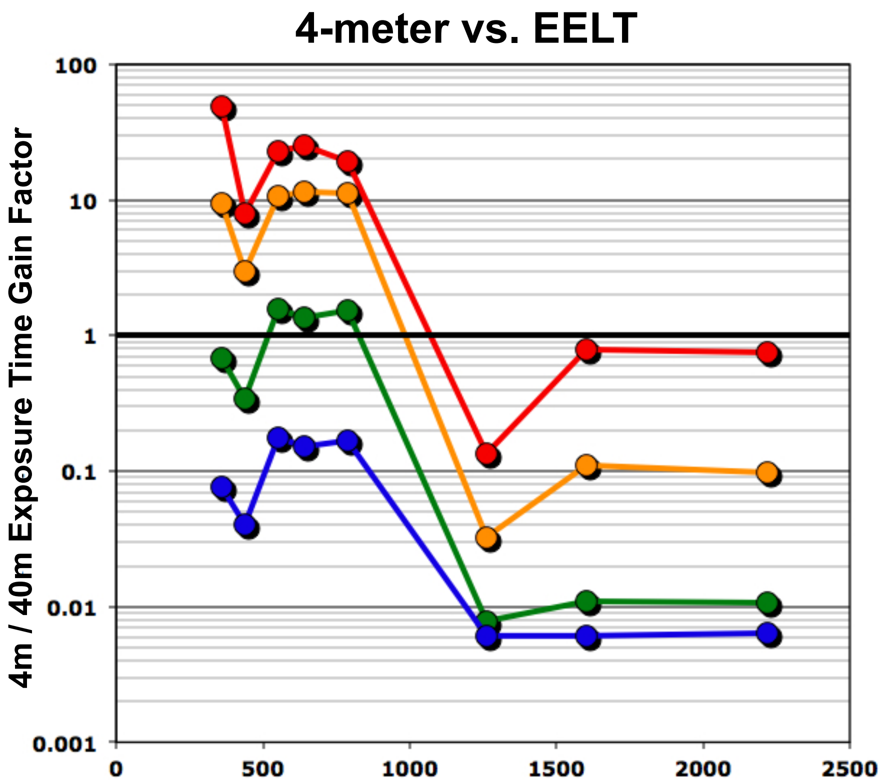
An 8-m can observe ~10 QSOs behind all galaxies within ~ 10 Mpc (purple line) and >1 QSO behind every galaxy out to 30 Mpc .

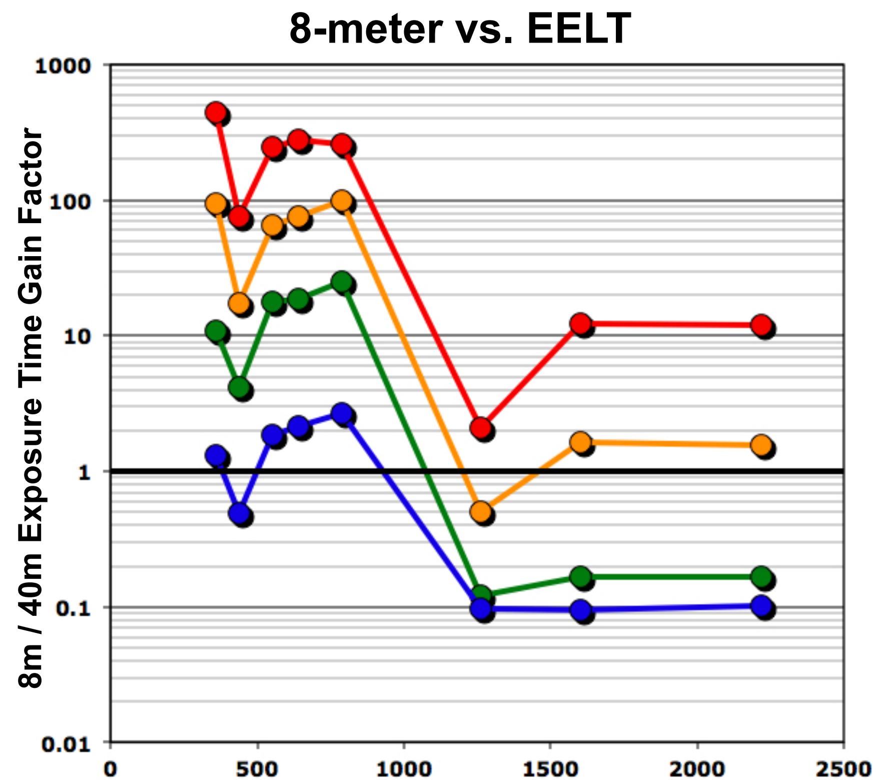
With such background source sampling we could dissect the gaseous halos of *the same local galaxy population* where we could measure the star formation histories from resolved stellar populations!

Considerations

- The science drivers for the next generation of problems require a major leap in space telescope aperture over HST.
- The unanticipated discoveries enabled by this next generation large space telescope will ensure its scientific relevance even with a decade-long timeframe from phase B to launch.
- We must be cognizant of the capabilities of upcoming facilities and instruments over the next 15 years:
  - JWST, WFIRST (possibly as a 2.4m telescope)
  - 20 – 30 meter ground-based optical/NIR telescopes, LSST
  - ALMA, SKA
- Astrophysics, as always, will advance from many facilities. But in the space UVOIR regime, a significant aperture increase for a narrow field observatory is required.

Exposure Time Ratio to Reach S/N = 10
(in Optical / NIR wavelengths)





Assumes 40m EELT seeing limited below 1 micron and diffraction limited above 1 micron

- ● R = 5, mag = 30
- ● R = 100, mag = 28
- ● R = 2,000, mag = 26.5
- ● R = 20,000, mag = 24

UV access is a unique AND important capability.

At longer wavelengths, 4m space telescope has ~20x speed gain for visible broad-band imaging over EELT in the optical but no advantage in NIR at any spectral resolution (except for panoramic imaging). And if WFIRST is a 2.4m we will have a comparable panoramic imaging application covered.

An 8-meter, or larger, space telescope, however, uniquely covers key observational regimes in the UV, optical, and NIR.

A “10-meter Class” UVOIR space telescope is essential if astrophysics and exoplanet research are to have vibrant and exciting long-term futures.

Science and Telescope Requirements Summary

Science Case	Observations	Implications
Characterize at least 50 Earth-like planets around solar type stars and search for bio-signatures.	High-contrast imaging (ΔMag>25 mag, R=5) and low-res (R= 70 - 100) spectroscopy with SNR=10 in HZ.	8m or larger aperture with stable 10^10 starlight suppression (implies high wavefront stability). Wavelength range 300 nm – 2 microns.
Develop a comprehensive model of star and galaxy formation and evolution across a broad range of environments.	Two to three color visible band photometry at SNR=5 for individual solar type stars below MSTO out to 10 Mpc.	8m or larger aperture with diffraction limited performance at 500 nm. Modest FOV (4-8 arcmin). Stable PSF.
How do galaxies and the IGM interact and what is the impact on their respective evolution?	SNR=20 high resolution (R=20,000) UV spectroscopy of QSO’s down to 23 – 24 mag in the FUV regime over a broad range of environments.	High efficiency UV detectors behind 8m class space telescope. UV wavelength coverage down to at least 1000 Angstroms (and preferably 900 Angstroms).

Concluding Thoughts

- UVOIR access from space is fundamental to understanding the universe and the life within it.
- “Game Changing” science requires substantial increase in aperture.
- Enabling such a capability requires alliances, so the exoplanet and astrophysics communities need to work together to make their next generation flagship space telescope the SAME mission.
- Need to encourage commitment to funding UVO technologies. Crucially, the technology advances needed for a “10-meter class” facility benefit UVOIR missions of all scales – even SMEX (e.g., light weight optics, active wavefront control, uniform UV coatings, photon-counting detectors, giga-pixel imagers).