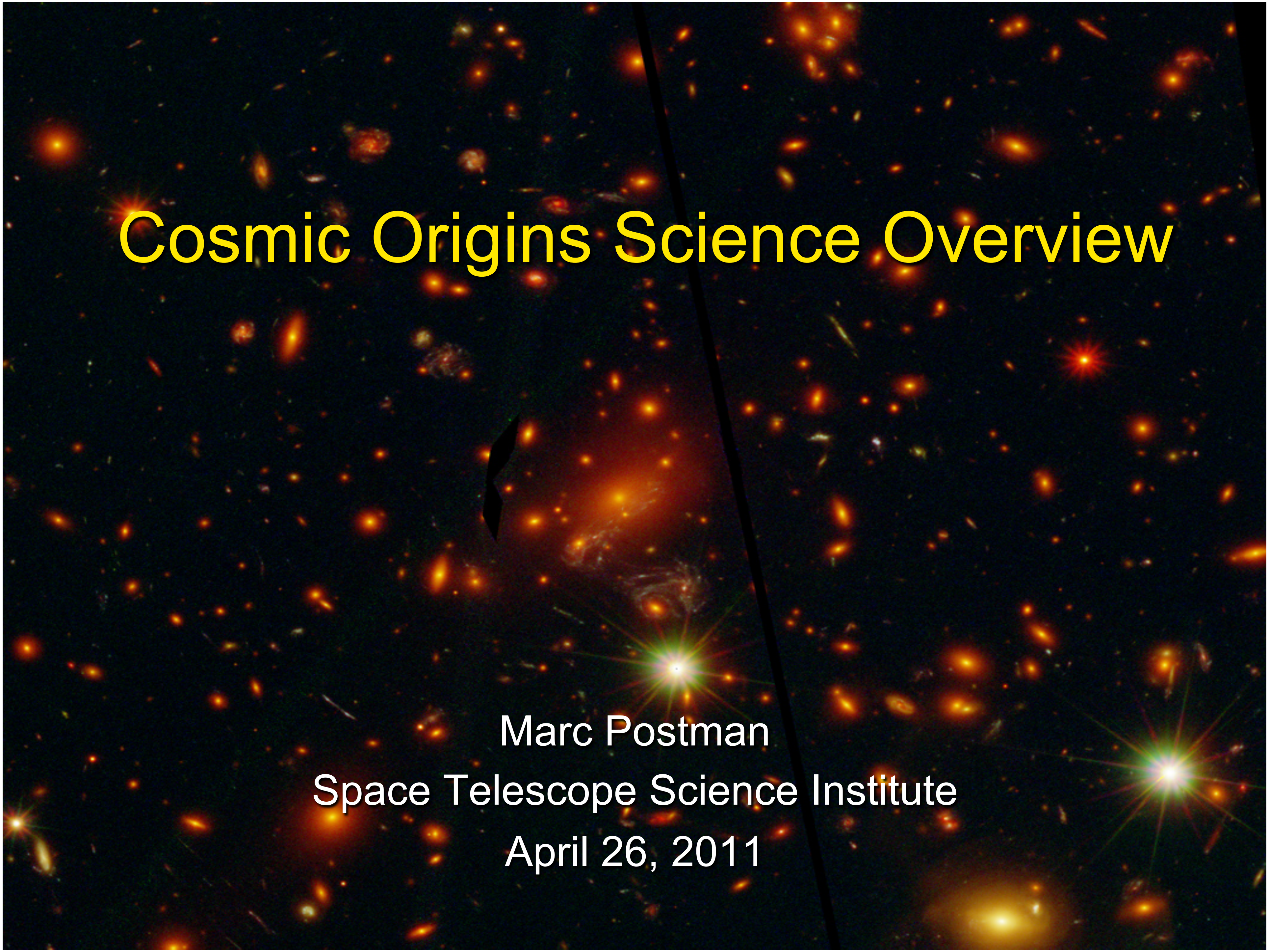


Cosmic Origins Science Overview

Marc Postman
Space Telescope Science Institute
April 26, 2011

Fundamental and, as yet, Unsolved Questions in Astrophysics

How did the present Universe come into existence and what is it made of?

- How do galaxies assemble their stars?
- How does Galaxy Feedback enrich and regulate the IGM?
- How does the mass of galactic structures increase with time?

Requires velocity and brightness measurements of very faint objects. Requires UV/optical spectra of faint sources in crowded fields.

What are the fundamental components that govern the formation of today's galaxies?

- How do super massive black holes evolve?
- Why is their mass correlated with that of their host galaxies?
- How is dark matter distributed within a galaxy?

Requires UV/optical spectra in central 200 pc of galactic nuclei. Needs high angular resolution & sensitivity. Need stable long-baseline imaging.

How do stars and their planets interact with the Interstellar medium that surrounds them?

- How does the local ISM modulate cosmic ray flux?
- How does stellar activity alter habitability and life?
- What is the typical structure of the astrosphere around a star?

Requires high-res UV absorption spectroscopy of stellar sources.

How does the Solar System work?

- What are the physical processes driving atmospheric chemistry and kinematics in the outer planets in our Solar System?

Requires UV spectroscopy of faint sources and high angular resolution UV/optical/NIR narrow band imaging.

"… if technology developments of the next decade show that a UV-optical telescope with a wide scope of observational capabilities can also be a mission to find and study Earth-like planets, there will be powerful reason to build such a facility." – Astro2010 EOS** Panel Report.

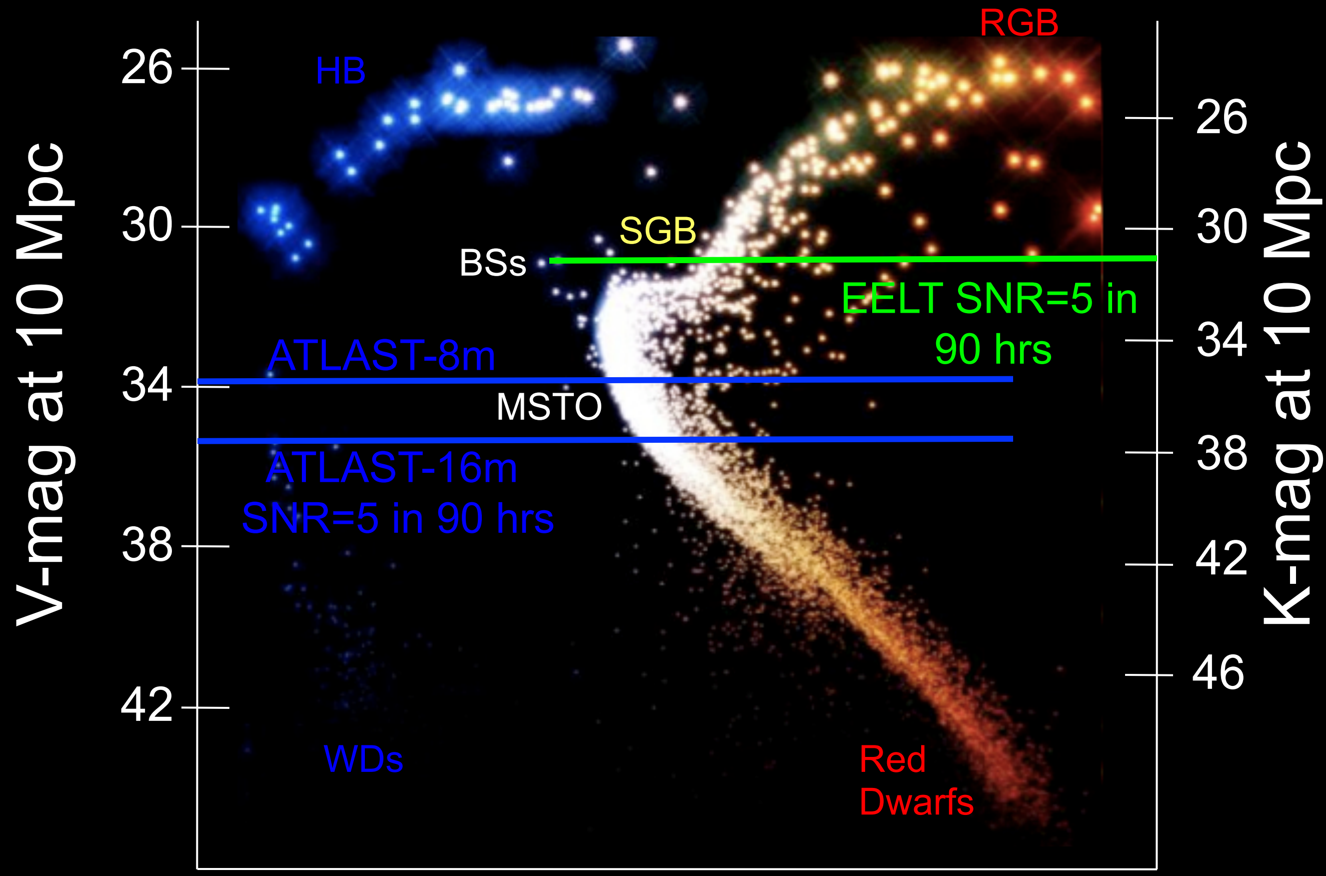
"… on the condition that the broad astronomical community can agree on a single UVOIR observatory concept by about 2017 …"

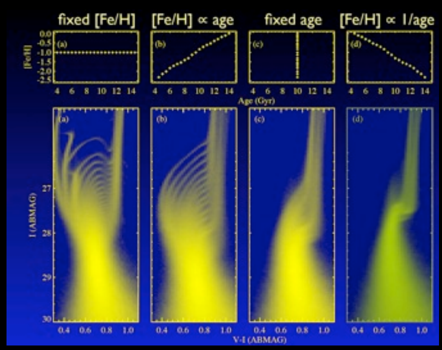
**Electromagnetic Observations from Space

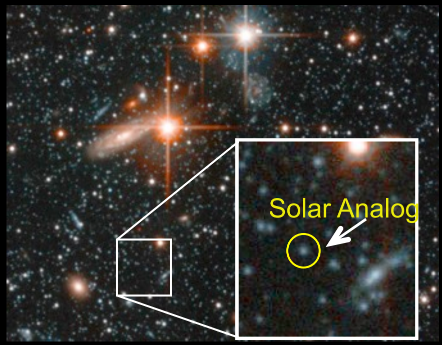
Future Science Drivers

- High Angular resolution coupled with high sensitivity is increasingly a science-driven requirement for astronomy. Need milli-arcsec & nanoJansky capability.
- Angular resolution that is MATCHED with the appropriate spectroscopic resolution is essential for a fuller interpretation (e.g., jet physics, disk formation processes).
- Angular resolution that is MATCHED with the mass and size scales being probed, across a broad wavelength range, can reveal complex physical processes.

An 8-m+ class ST could detect the Main Sequence Turn-Off in Galaxies up to 10 Mpc Away



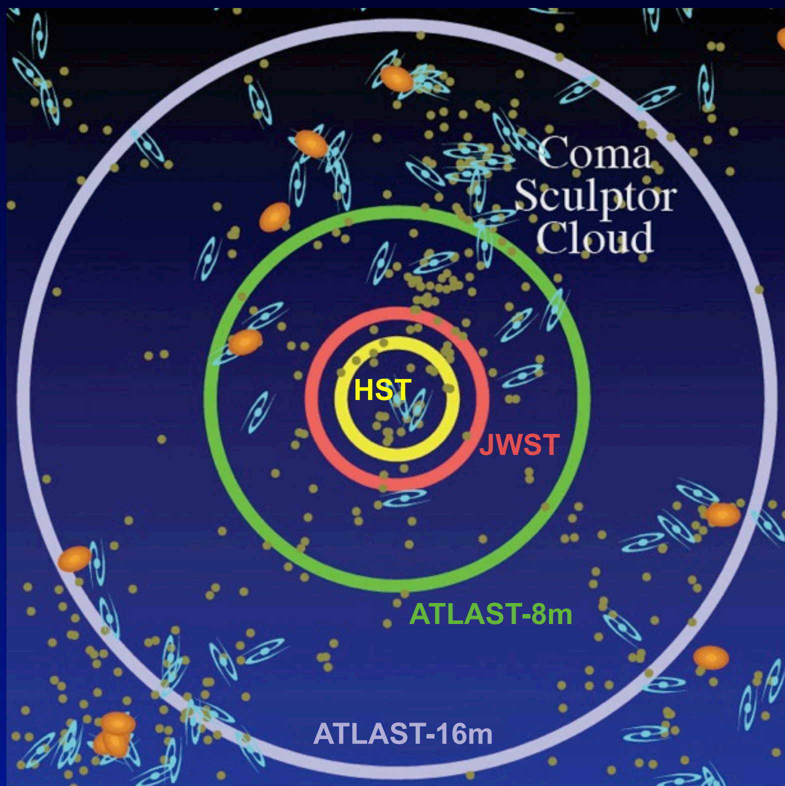


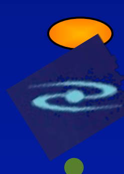


CMD image: J. Anderson
Flux scale: K. Olsen et al. 2009

What is the Star Formation History of Galaxies as f (M,T,env) and is the IMF Universal?

Galaxies within 12 Mpc of Our Galaxy

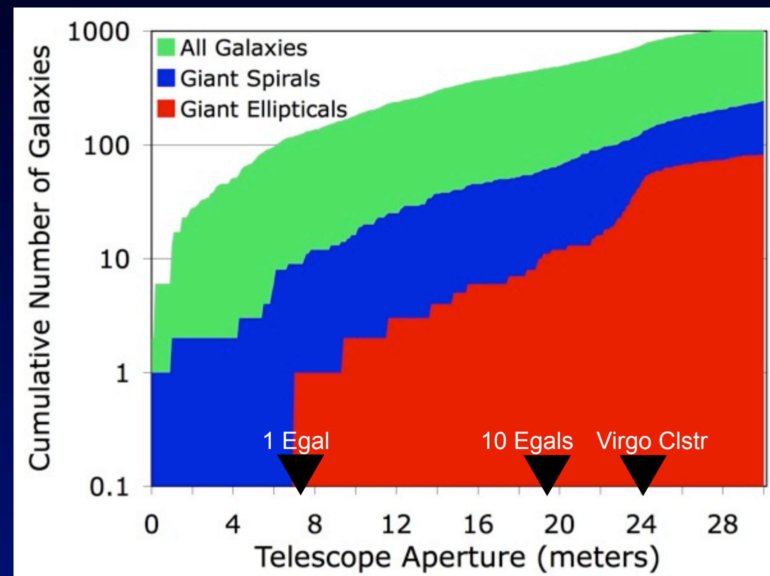




= Large Elliptical Galaxy

= Large Spiral Galaxy

= Dwarf Galaxy



An 8-m (or larger) space telescope will detect individual solar type stars in the main sequence in nearby Elliptical galaxies.

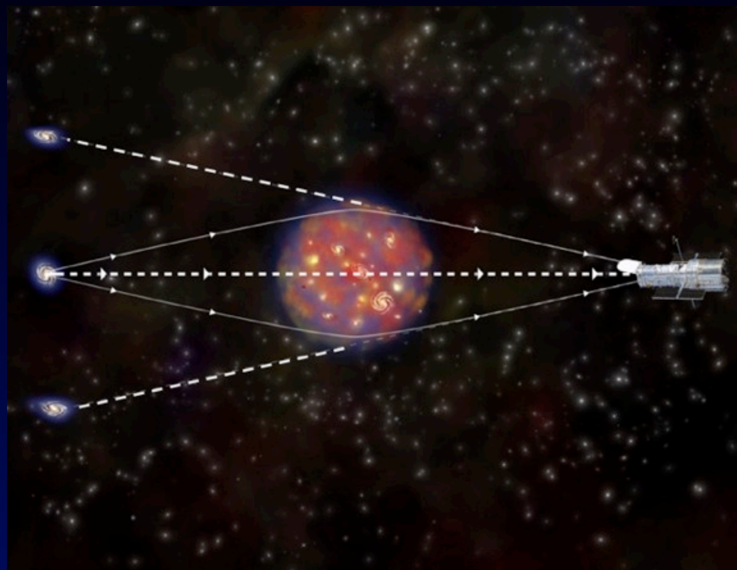
This will yield a major breakthrough in our understanding of how galaxies assemble their stars. No other planned facility will have this capability.

Exquisite Angular Resolution in the Visible Spectral Range

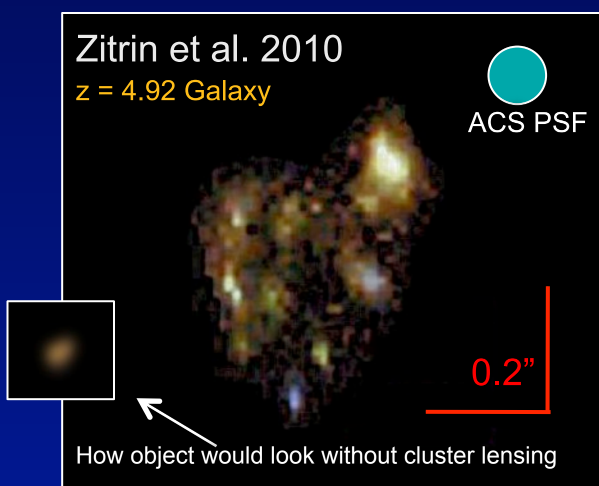
Image credits: T. Lauer

Above: The center of M31 in 3 optical passbands (U,V,I)

Gravitational Lensing: A Glimpse of What Could be Routine for ANY High-z Galaxy?



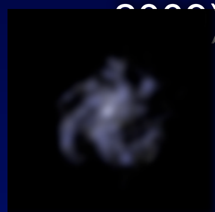
Highly Magnified z ~ 5 galaxies

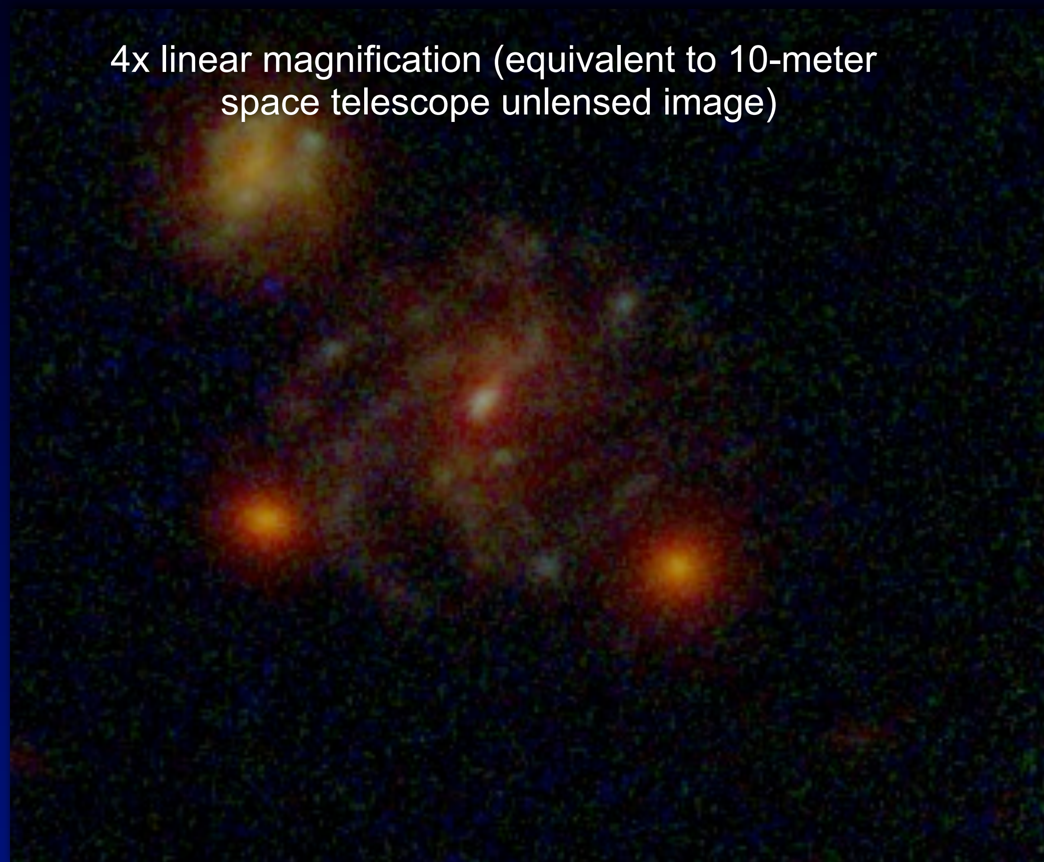


- Reconstruction of a z = 4.92 source lensed by the z = 0.33 cluster MS1358+62.
- Best resolved high-z object: spatial resolution of ~50 pc (rest-frame UV)
- *Equivalent to 20-m space telescope resolution of a non-lensed z=5 galaxy!*

Gravitational Lensing: A Glimpse of What Could be Routine for ANY High-z Galaxy?

Unlensed source (based on GL model by Zitrin et al. 2009)





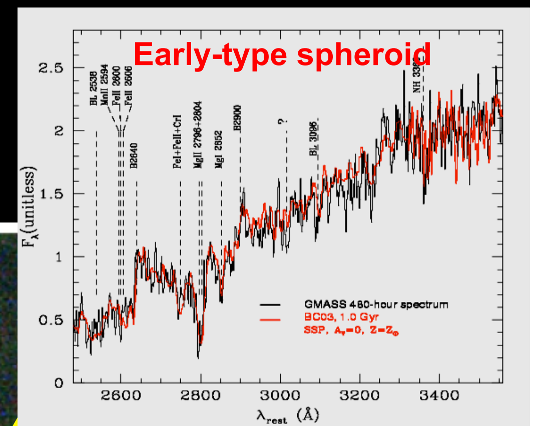
MACS 1149+2223

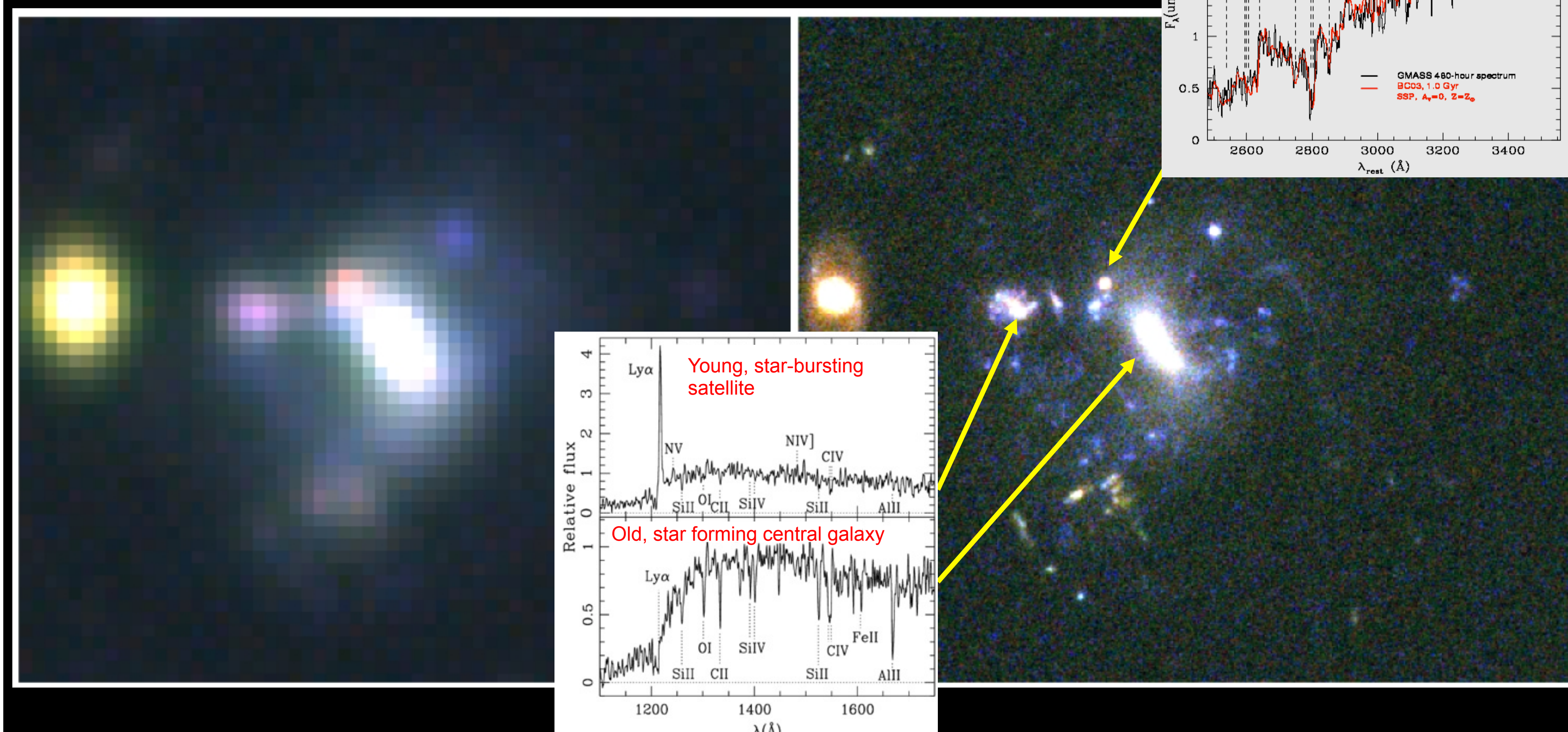
(z = 1.49 Spiral)

“Modern” Galaxy Evolution

Track how and when galaxies assemble their present stars
Investigate why galaxies start to evolve passively
Test the hierarchical formation of structure

We require high ang. resolution & hi-sensitivity access to UV-Vis diagnostics



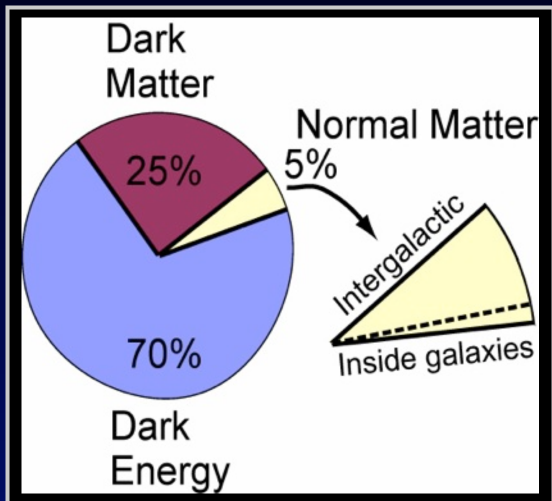


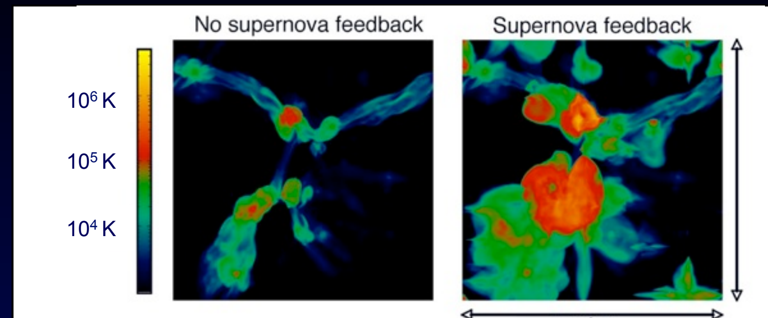
Galaxy at z~3 with HST (100 mas FWHM)

Galaxy at z~3 with ATLAST (10 mas FWHM)

Understanding the Galaxy - IGM Interplay

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





Cen & Ostriker 2006

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

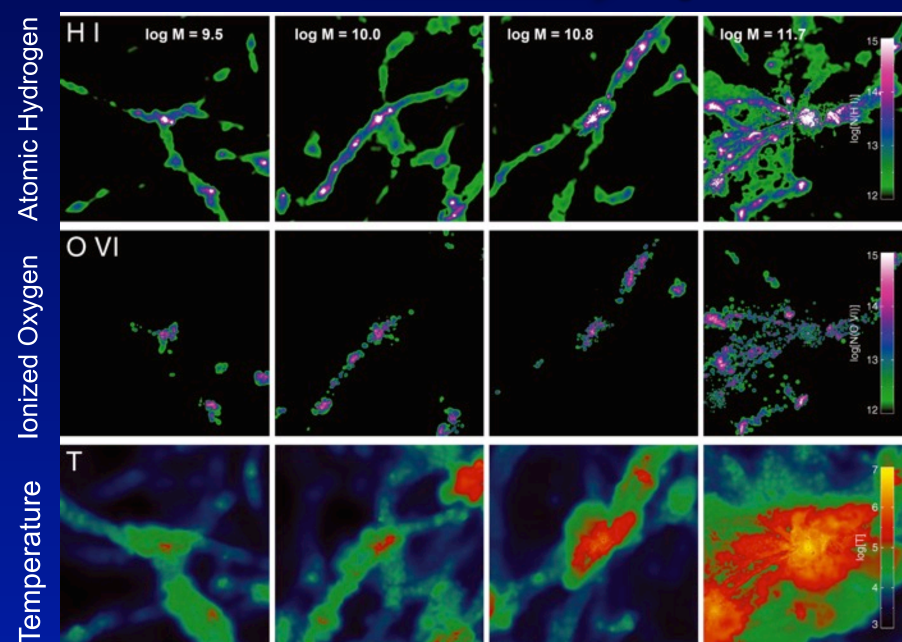
Understanding how gas in the intergalactic medium (IGM) gets into galaxies and how galaxies respond to inflow lies at the heart of understanding galactic evolution.

Depending on the mass of the galaxy halo, infalling gas may be shocked and heated or accrete in cold mode along narrow filaments. Gas can also be *removed* from galaxies via tidal and ram pressure stripping, supernova-driven winds, or during the accretion of gas-rich dwarfs onto giant galaxies.

These predictions need to be tested

Below: Gas ionization and Temperature Distribution vs. Galaxy Mass

Lower Mass → Higher Mass



Oppenheimer et al. 2009

Understanding the Galaxy - IGM Interplay

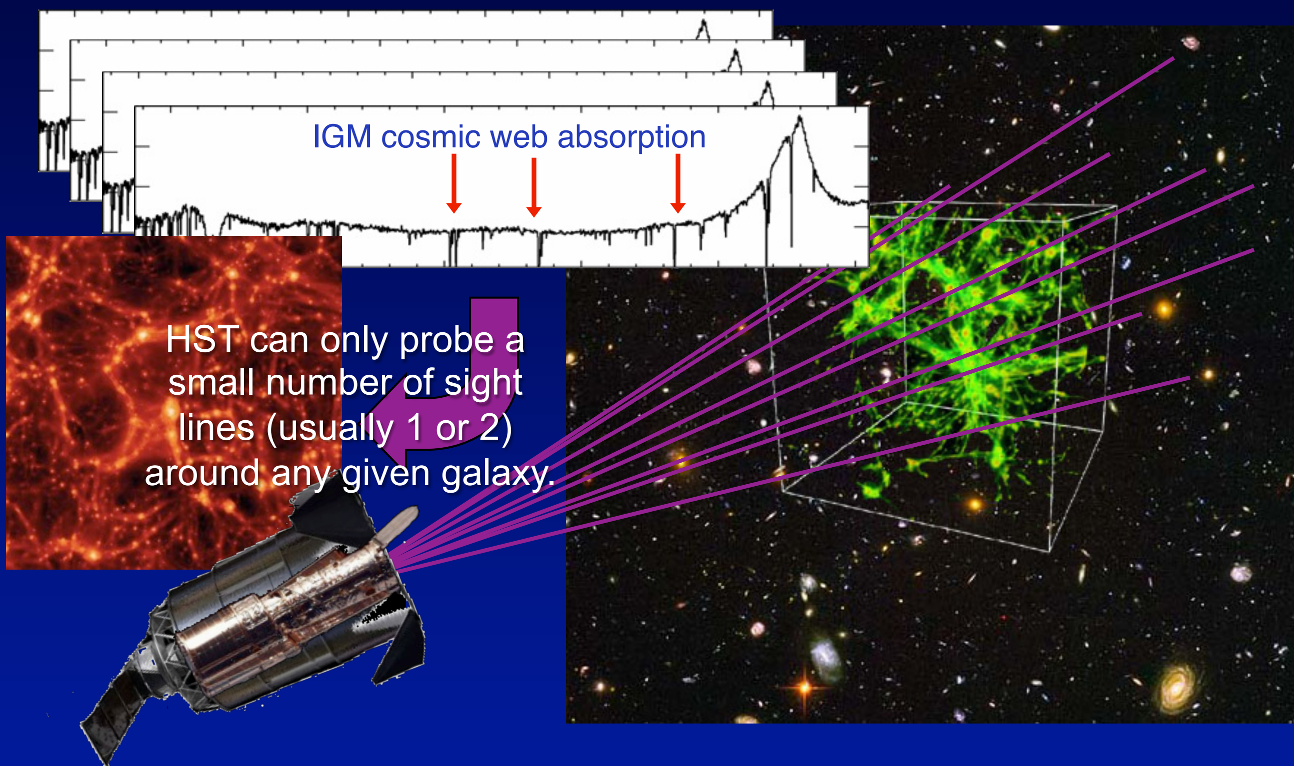
The key questions are:

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?

All of these accretion and gas removal theories have observational consequences that can be tested if the distribution of gas in the cosmic web around galaxies can be characterized through UV absorption and emission line spectroscopy with a larger UV Space Telescope.



Dramatically increased absorption line sensitivity at UV and optical wavelengths is crucial for reaching the required background source densities: ~100 quasars per square degree.

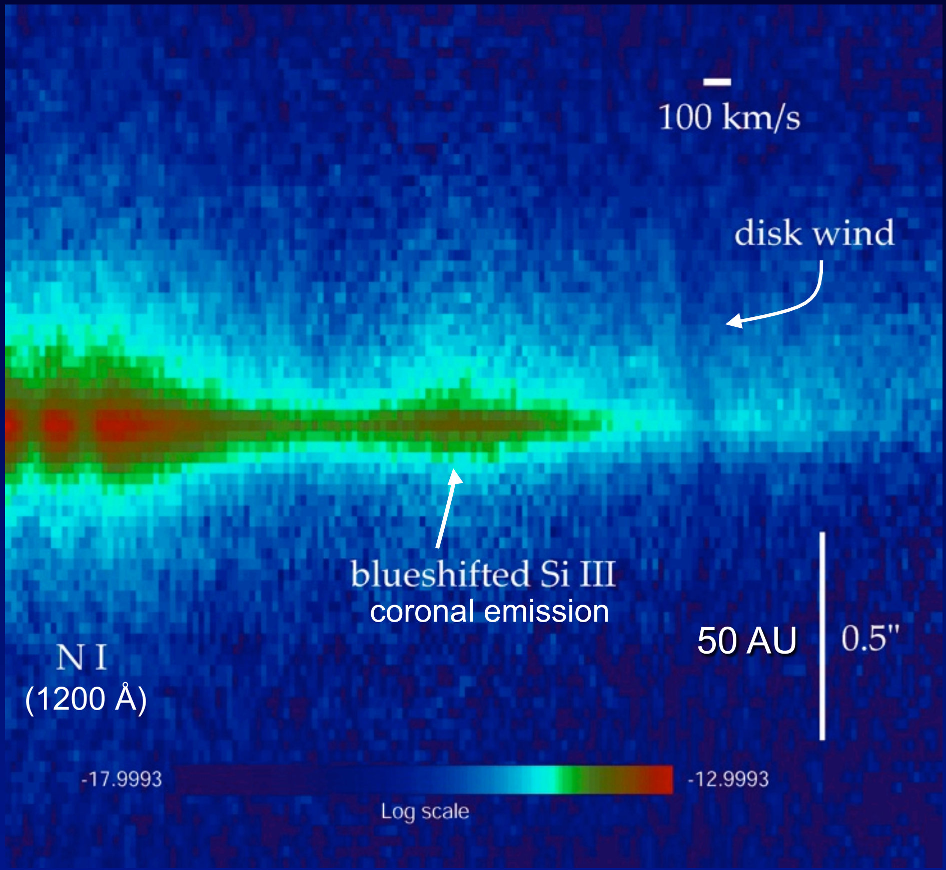
Must be able to get S/N=20 R=20,000 spectra of GALEX FUV 24 mag sources to explore full range of galaxy parameter space.

This is well below HST/COS sensitivity but is easily reachable with 4m – 8m space telescope.

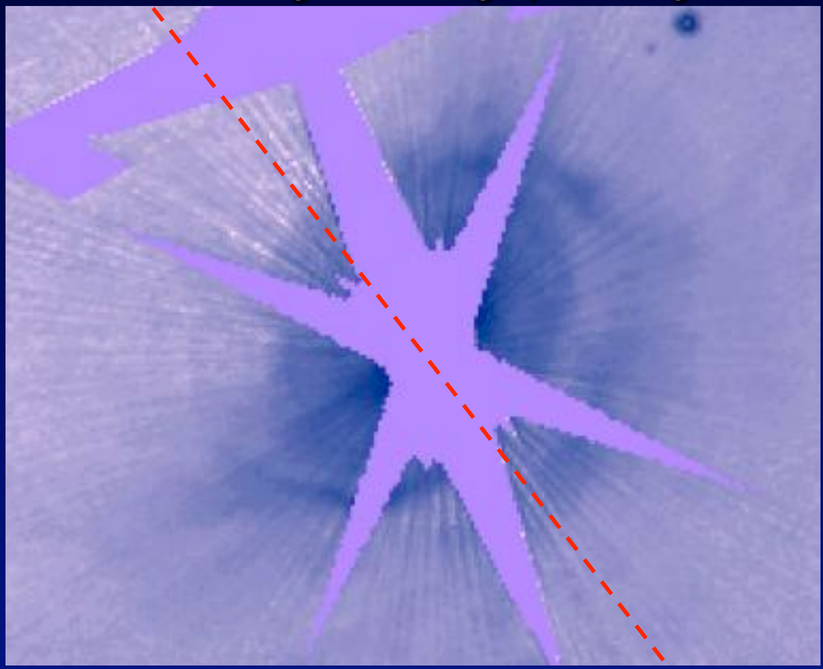
A large UVOIR Space Telescope will yield a high-resolution map of the gas and metals surrounding thousands of galaxies.

Early Evolution of Proto-planetary Disks

Combination of high-spatial AND spectral resolution yields first confirmed detection of a wind associated with a proto-planetary disk (HD 100546). Advantage of UV: Coronal Ly-α spectral region is dark, enabling "coronagraphic" quality imaging at small angular separations from central star.



STIS White Light Coronagraphic Image



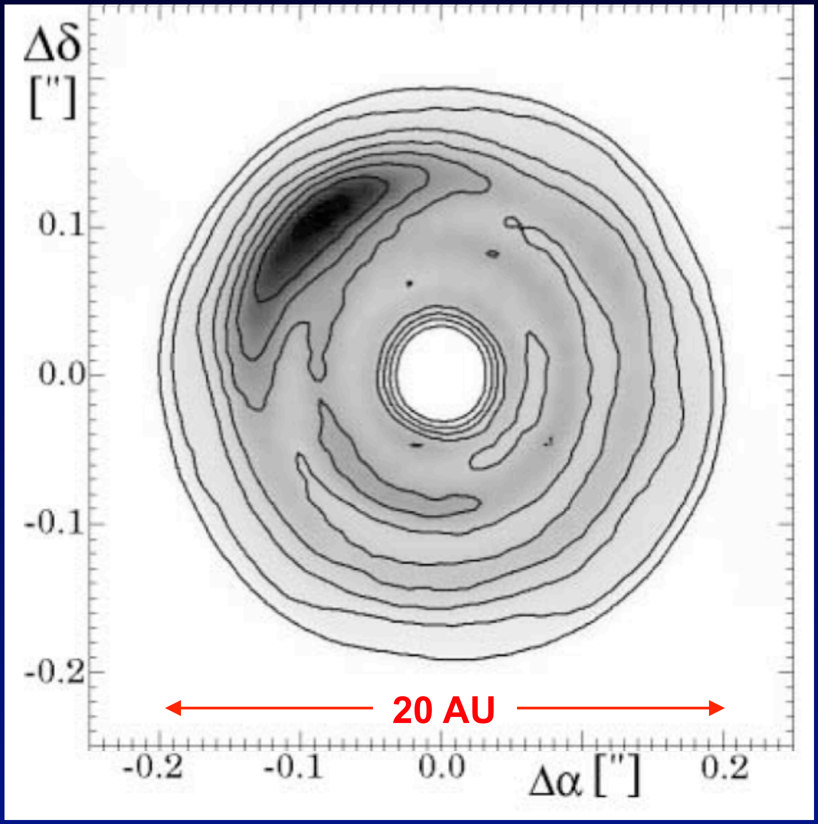
80 AU

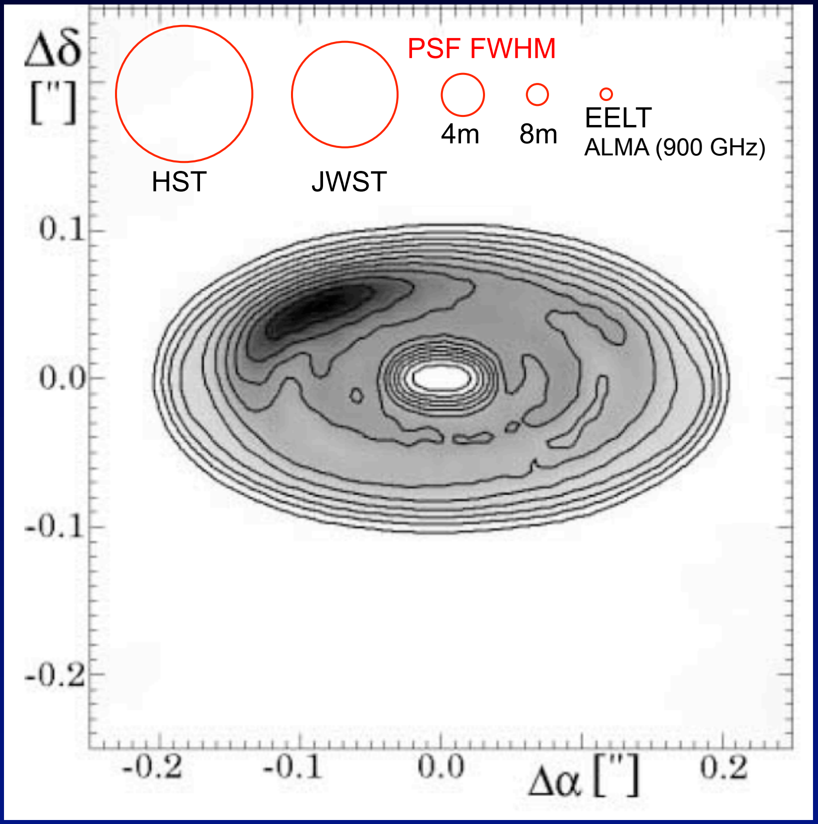
Slit Orient.

Grady et al. ApJ, 2005

Early Evolution of Proto-planetary Disks

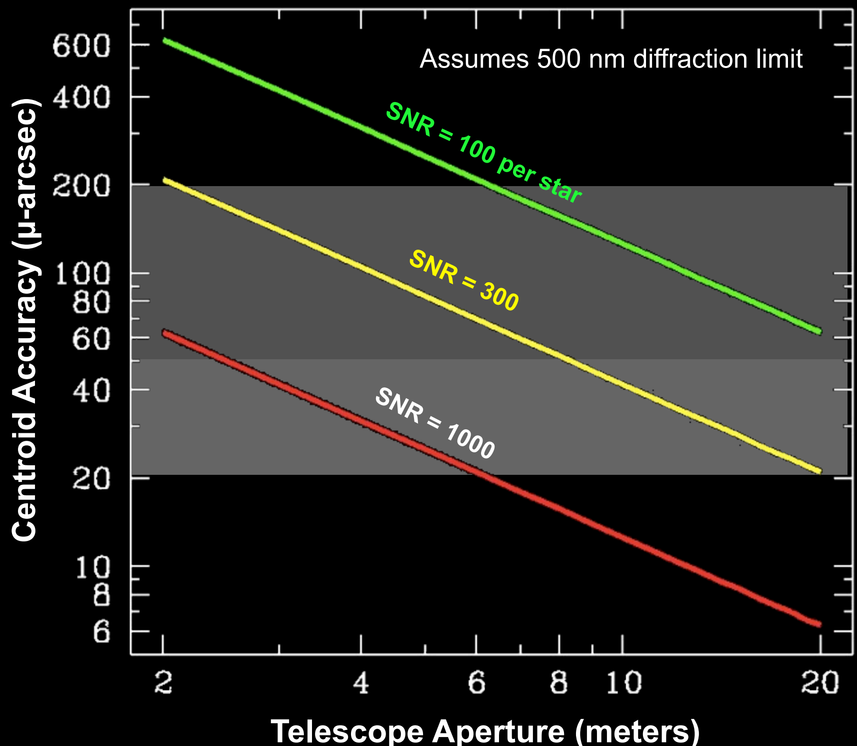
Simulated ALMA 900 GHz images of protoplanetary disk at distance of 50 pc (Wolf & Klahr ApJ, 2002)





Mapping Dark Matter in the Local Group

Centroiding Error ≈ (PSF size)/SNR

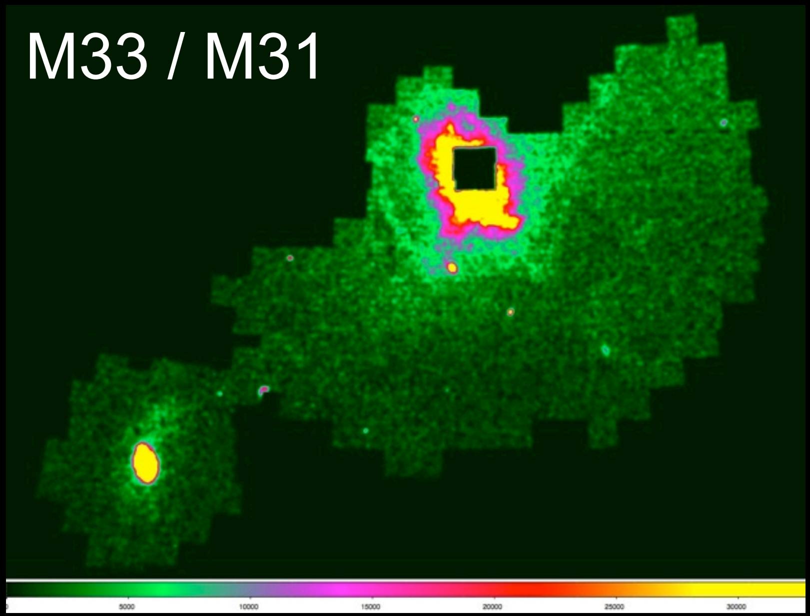


LG kinematics: 50 - 200 μ-asec in 5 years
Virgo kinematics: 20 - 50 μ-asec in 5 years

Long time baseline requires high-accuracy calibration of focal plane stability

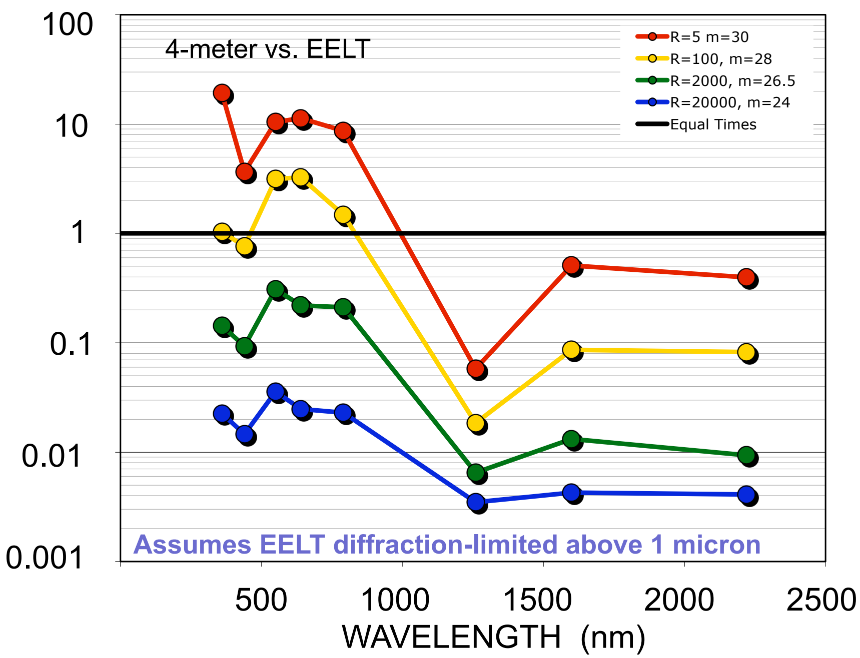
There are at least 20 dwarf galaxies in the Local Group, with more likely to be discovered in the coming decade. Dwarfs are dark-matter dominated systems, whose density profiles tell us much about the nature of the DM.

A large UVOIR space telescope can measure the proper motions of the stars in these dwarf galaxies allowing accurate constraints of the mass of the Local Group and the density profile of DM. TMT/EELT will provide essential radial velocities needed for full 3D dynamical studies.



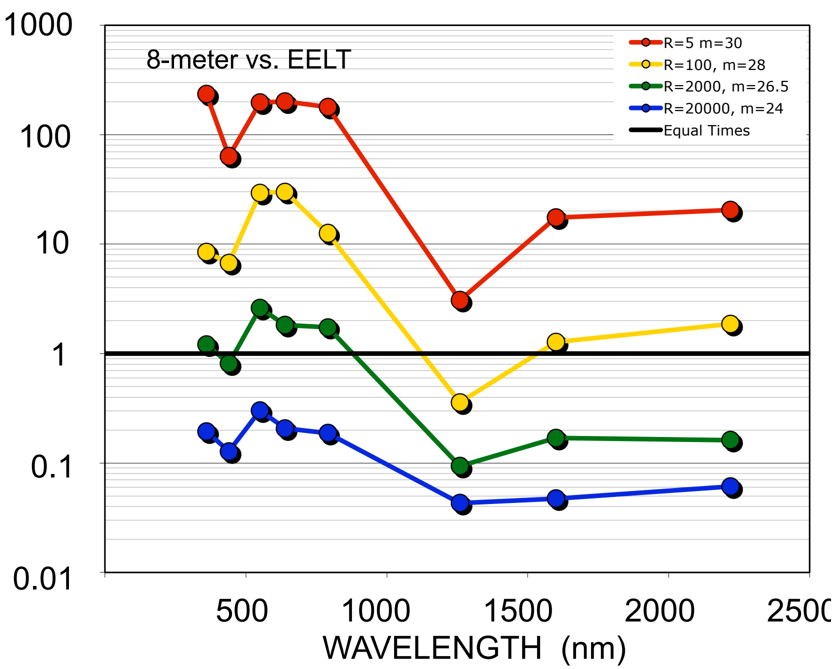
The structures shown here are resolved into stars. Over a baseline of 4-5 years, a large UVOIR space telescope could measure proper motions for the major structures and dwarf spheroidal galaxies of the M31/M33 halo system.

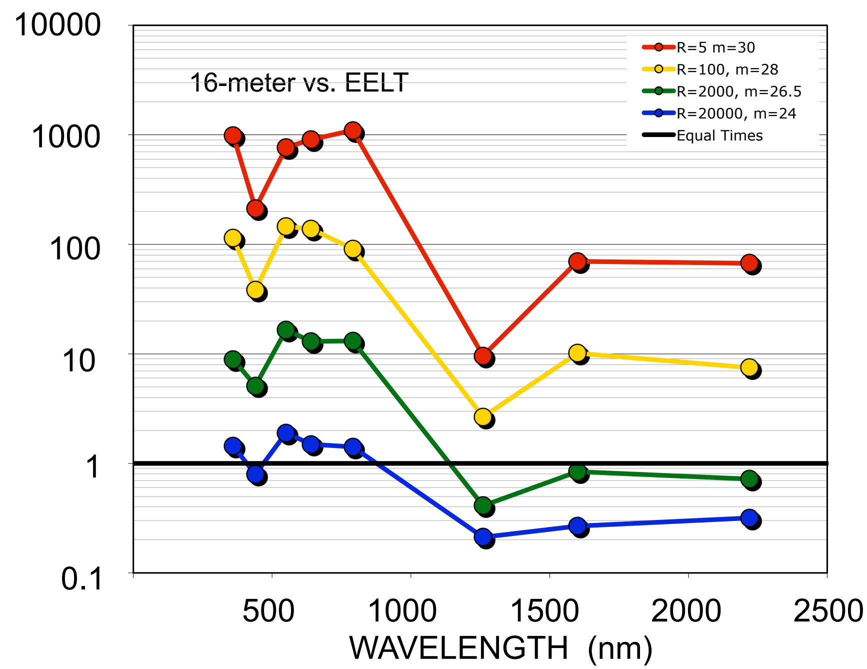
S/N=10 Time Gain Comparison



A 4-meter space telescope in the post-JWST / EELT era (ca. 2030) is *not likely to be* competitive in the arena of general astrophysics **(except in UV)**. An 8m – 16m telescope maintains unrivaled capabilities across a broad UVOIR wavelength and spectral resolution range.

4m @ 500nm = 31.5 mas	16m @ 500 nm = 7.9 mas
8m @ 500nm = 15.7 mas	42m @ 1200 nm = 7.2 mas

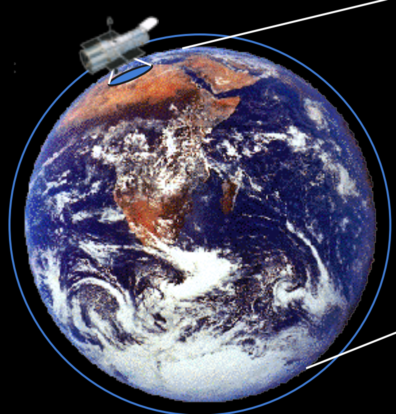


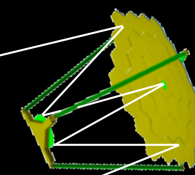


Earth Observations from Space

Benefits of HEO:

- Long dwell times on target: continuous coverage
- Large field of view on Earth ⇒ high information / image
- Few satellites to cover surface
  - LEO ⇒ 90 satellites, 200 km FOV
  - GEO ⇒ 3 satellites, 10,000 km FOV





$0.3 \lesssim \lambda \lesssim 20\ \mu m$

- Surveillance: 10 cm (r_0)
  - 45 mas @ LEO: 2-3 m (KH series)
  - 0.6 mas @ GEO: ~200 m (0.5 μm)
- Surveillance: 1m
  - 5.8 mas @ GEO: ~20 m (0.5 μm)
- Earth Science: >10m
  - >58 mas @ GEO: <4 m (1 μm)
  - >6 mas @ Moon: <21 m (0.5 μm)

Courtesy S.Beckwith

The Cosmic Origins Science Case for a Large UVOIR Space Telescope is Compelling

- Breakthroughs in the fields of star and galaxy formation and evolution require 10 – 20 mas angular resolution at 500 nm, with high sensitivity down to 110 nm.
- Imaging in crowded fields that span 5 – 10 arcminutes.
- Imaging of <1 nJy sources; spectroscopy of ~10 - 100 nJy sources.
- Synergy with and follow-on to planned facilities: ALMA, JWST, GMT, EELT, TMT, …
- Our next generation UVOIR telescope in space must allow ample capabilities to pursue science we cannot imagine today.