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CELEBRATING the INTERNATIONAL year of ASTRONOMY 2009

WINTER 2009 LSA Theme Semester www.lsa.umich.edu/universe

All lectures are on Fridays at 7:30 p.m.
1800 Dow Chemistry Building, 930 N. University Ave., Ann Arbor
Lectures followed by telescope viewing at Angell Hall Observatory

distinguished speaker series

JANUARY 23

Witnessing the Formation of Galaxies: Violence in the Young Universe

- Charles C. Steidel
  California Institute of Technology
  Orren C. Mohler Prize Lecture

FEBRUARY 6

A Revolution in Planetary Science: The Three-Zoned Solar System

- S. Alan Stern
  Former NASA Associate Administrator

FEBRUARY 20

Unveiling a Black Hole at the Center of Our Galaxy

- Andrea Ghez
  University of California at Los Angeles
  2008 MacArthur Fellow

MARCH 13

Binary Pulsars and Relativistic Gravity

- Joseph H. Taylor, Jr.
  Princeton University
  1993 Nobel Prize winner

APRIL 3

The Future of our Universe: From the 21st Century to the End

- Fred C. Adams
  University of Michigan
  1996 Warner Prize winner

Background image: The Eta Carinae nebula imaged by the *Hubble Space Telescope* (courtesy European Space Agency and NASA)

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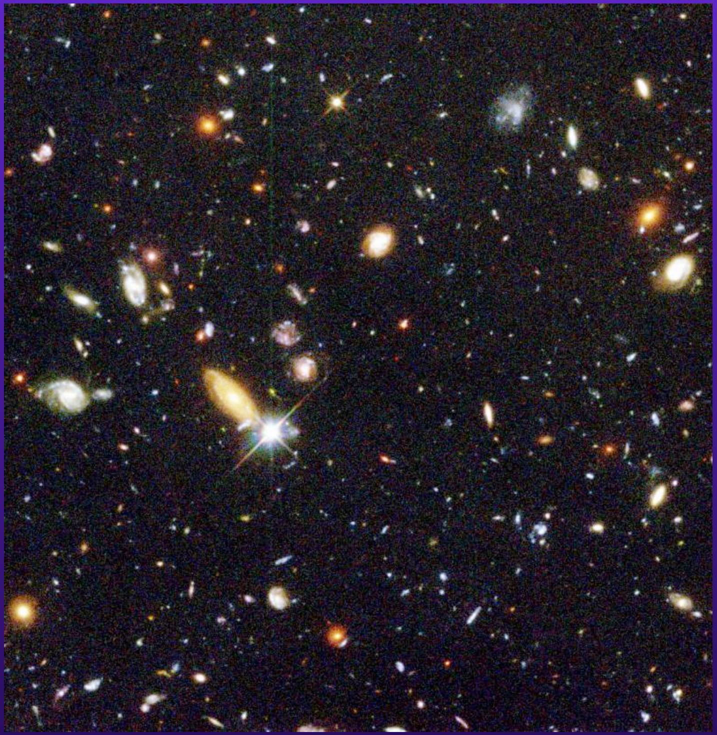
art of the Winter 2009
rse: Yours to Discover.
734-764-0478, or visit
du/universe

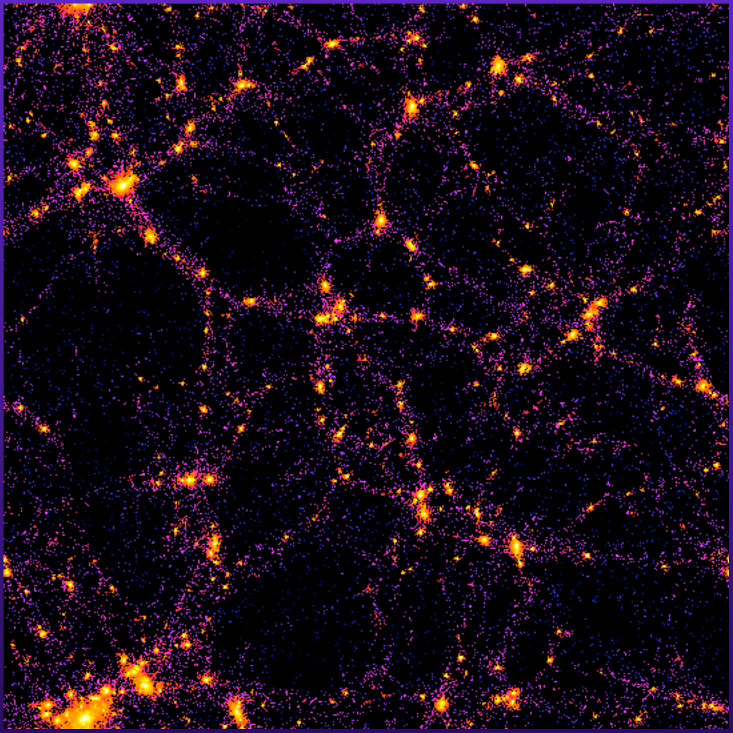
Presented by the Department of Astronomy, the Exhibit Museum of Natural History, and the Student Astronomical Society, and sponsored by the Michigan Center for Theoretical Physics, the University Activities Center, and the College of Literature, Science, and the Arts.

MLSA College of Literature, Science, and the Arts

Witnessing the Formation of Galaxies: Violence in the Young Universe

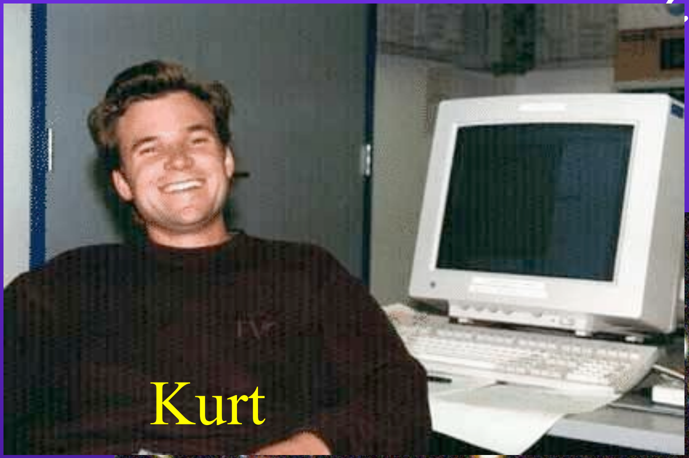
Chuck Steidel (Caltech)

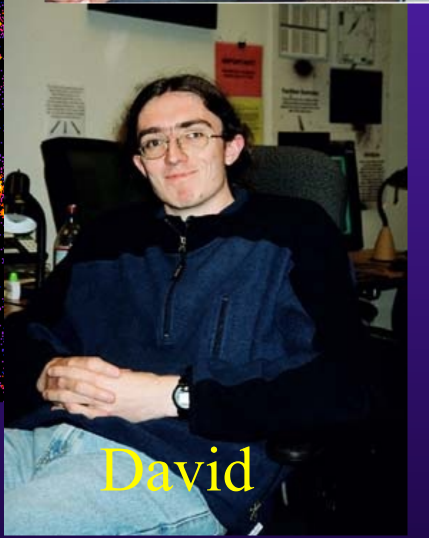




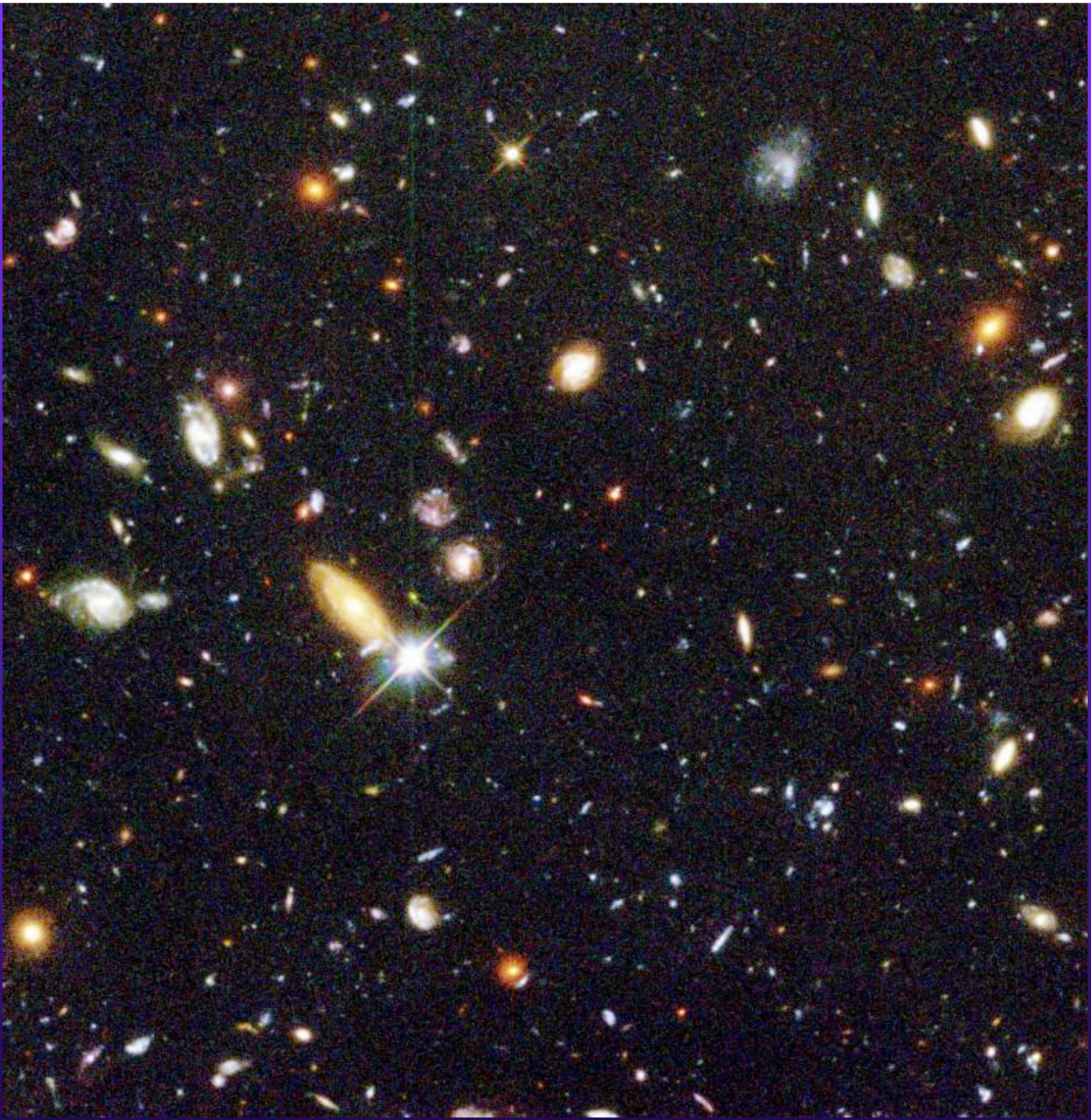
Witnessing the Formation of Galaxies: Violence in the Young Universe

Chuck Steidel



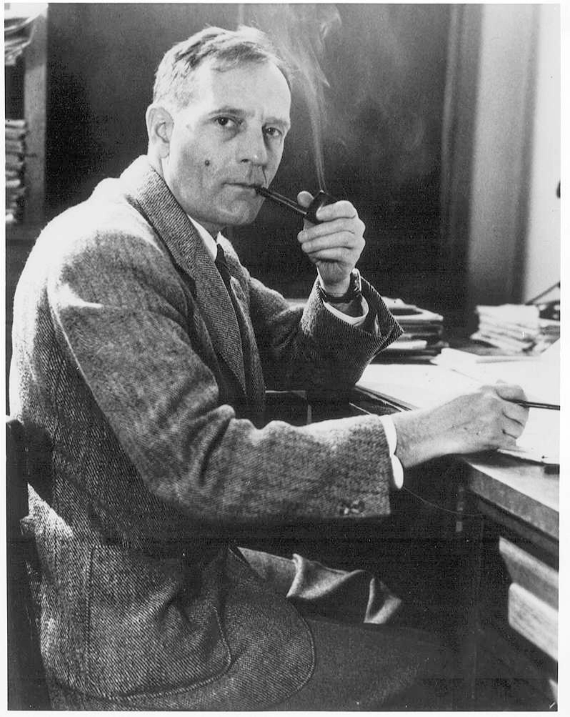


All photos by B. Schaefer, WMKO

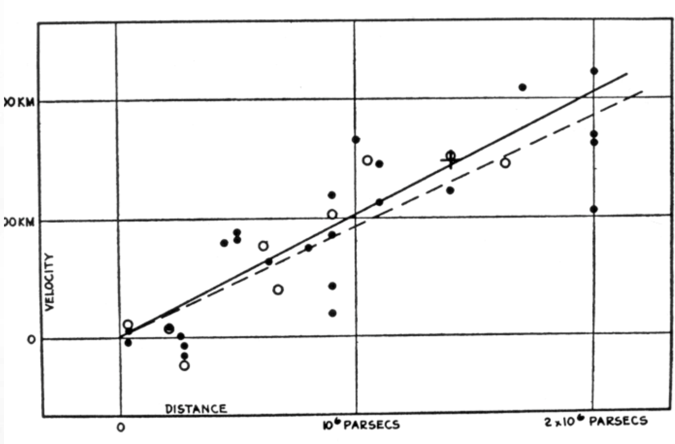


Hubble Deep Field, 1996

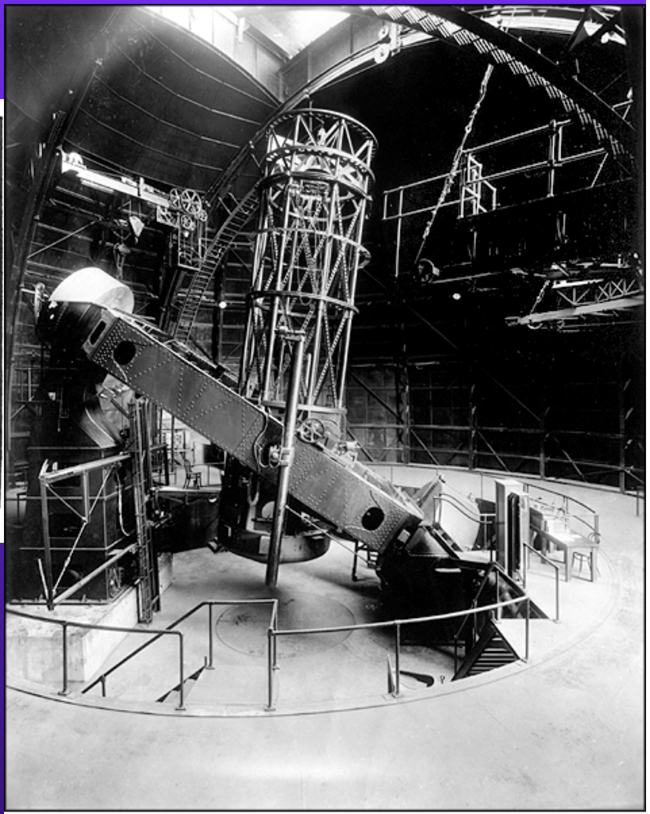
Discovery of the Expanding Universe



Edwin Hubble (1929)



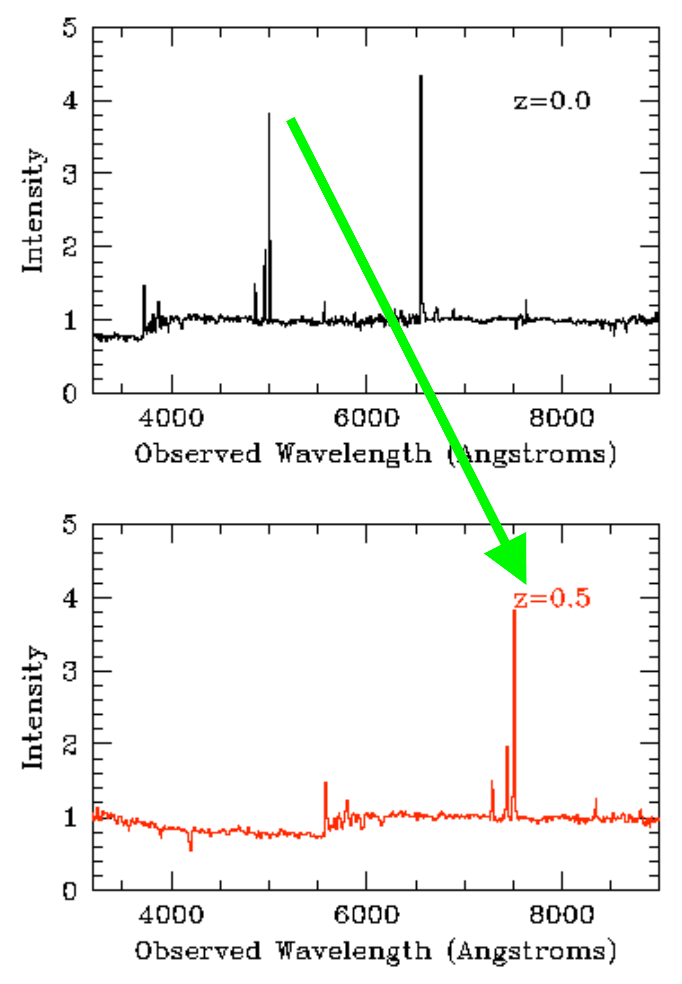
The Hubble diagram
(1936)



Copyright Digital Image Smithsonian Institution, 1998

Mt. Wilson 100″ telescope

Consequences of an Expanding Universe



$\lambda_{obs} = \lambda_{lab}\,(1+z)$

Where z is the "Redshift"

So, the spectrum of a galaxy carries information about the cosmic time at which the light was emitted, in addition to the physical information carried by the spectral features

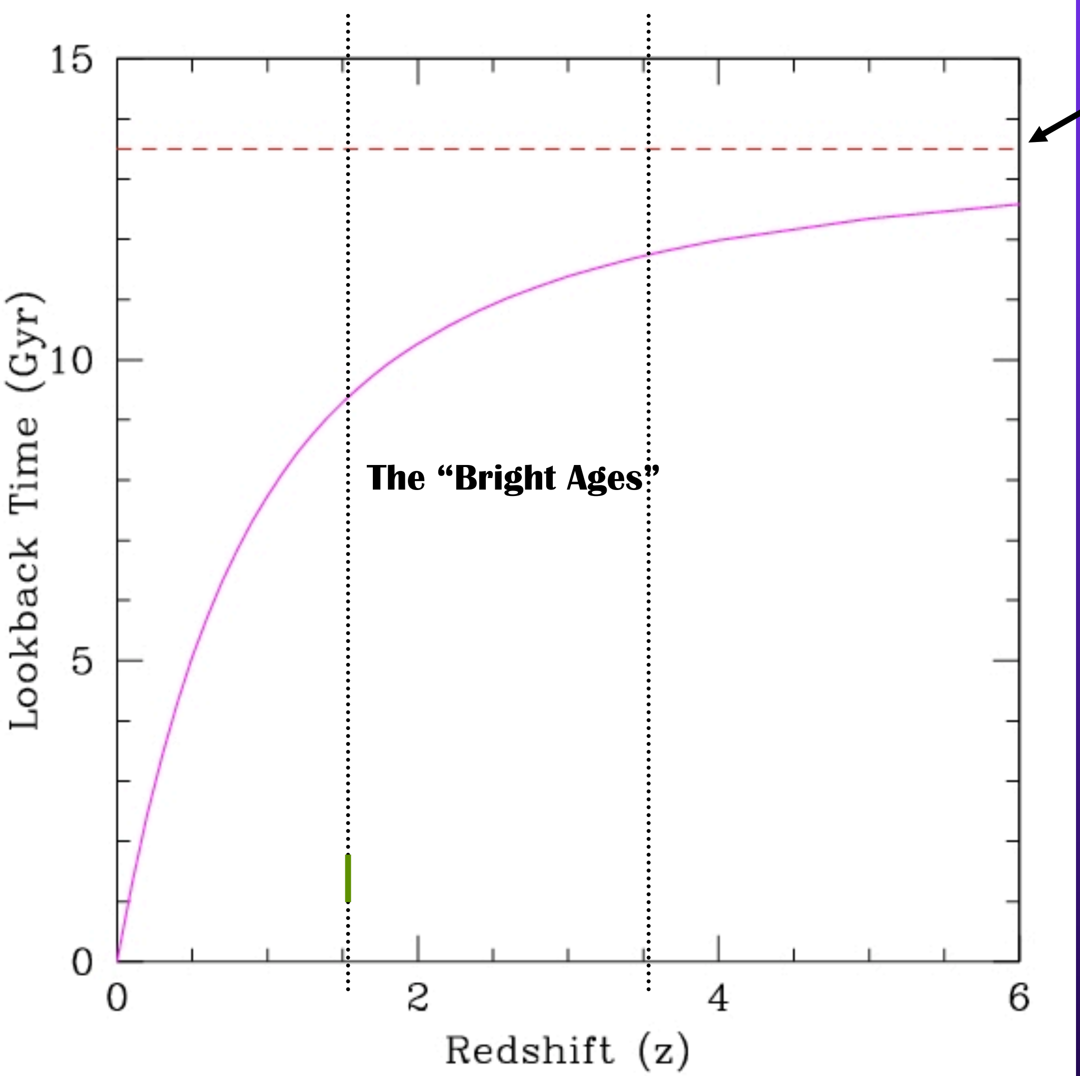
More About Redshift...

This factor (1+z) is directly related to the relative size of the universe at the time the light was emitted, compared to the present epoch, so, e.g.,

At redshift z=3, the universe was 4 times smaller, 64 times more dense, and about 80% younger than the present universe

Redshift is the directly measurable quantity that "maps" onto time and distance

Universal Timeline



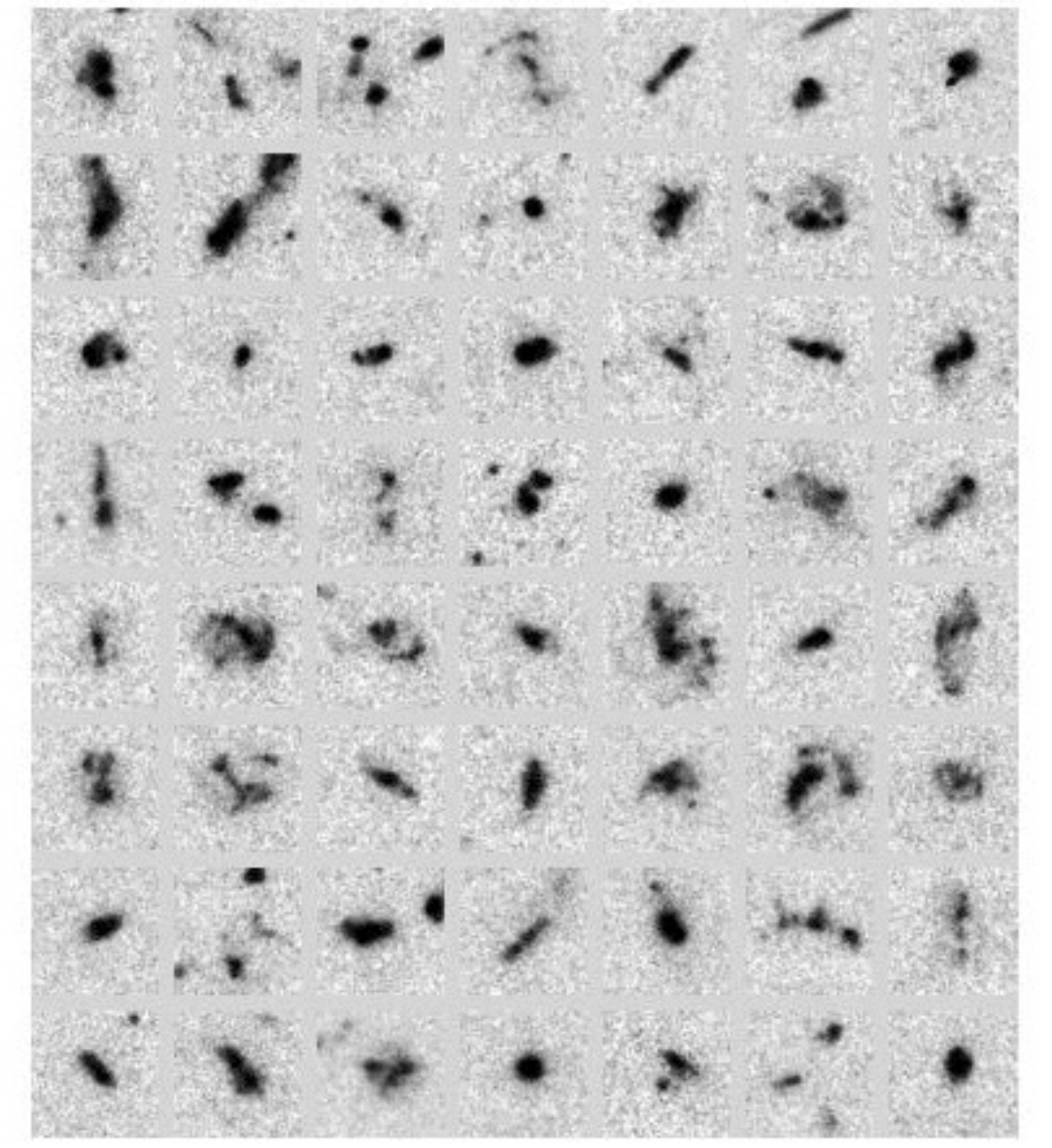
Best current estimate of the age of the universe (13.7 billion years)

It appears that the era that dominates the assembly of galaxies was 9-12 billion years ago ...

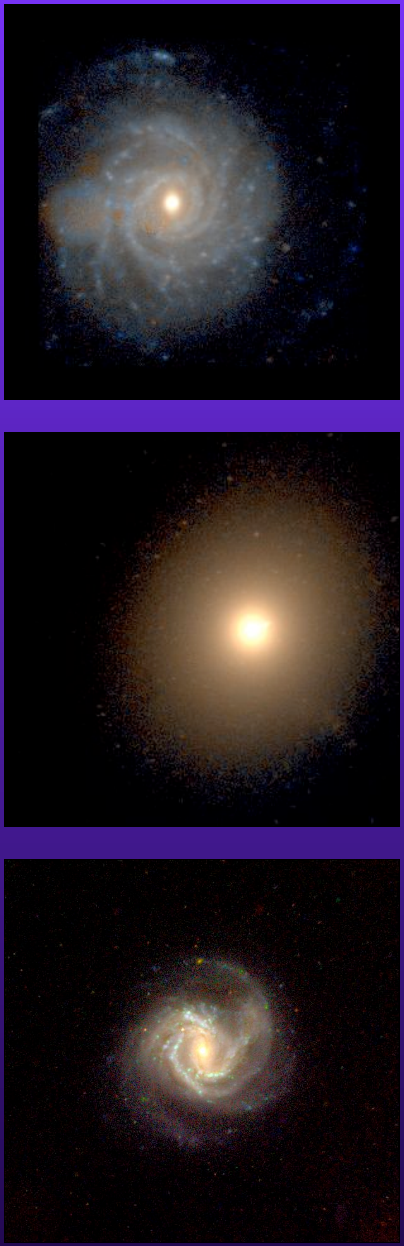
This was also the time when quasars, the most energetic phenomenon in the universe's history, peaked in activity.

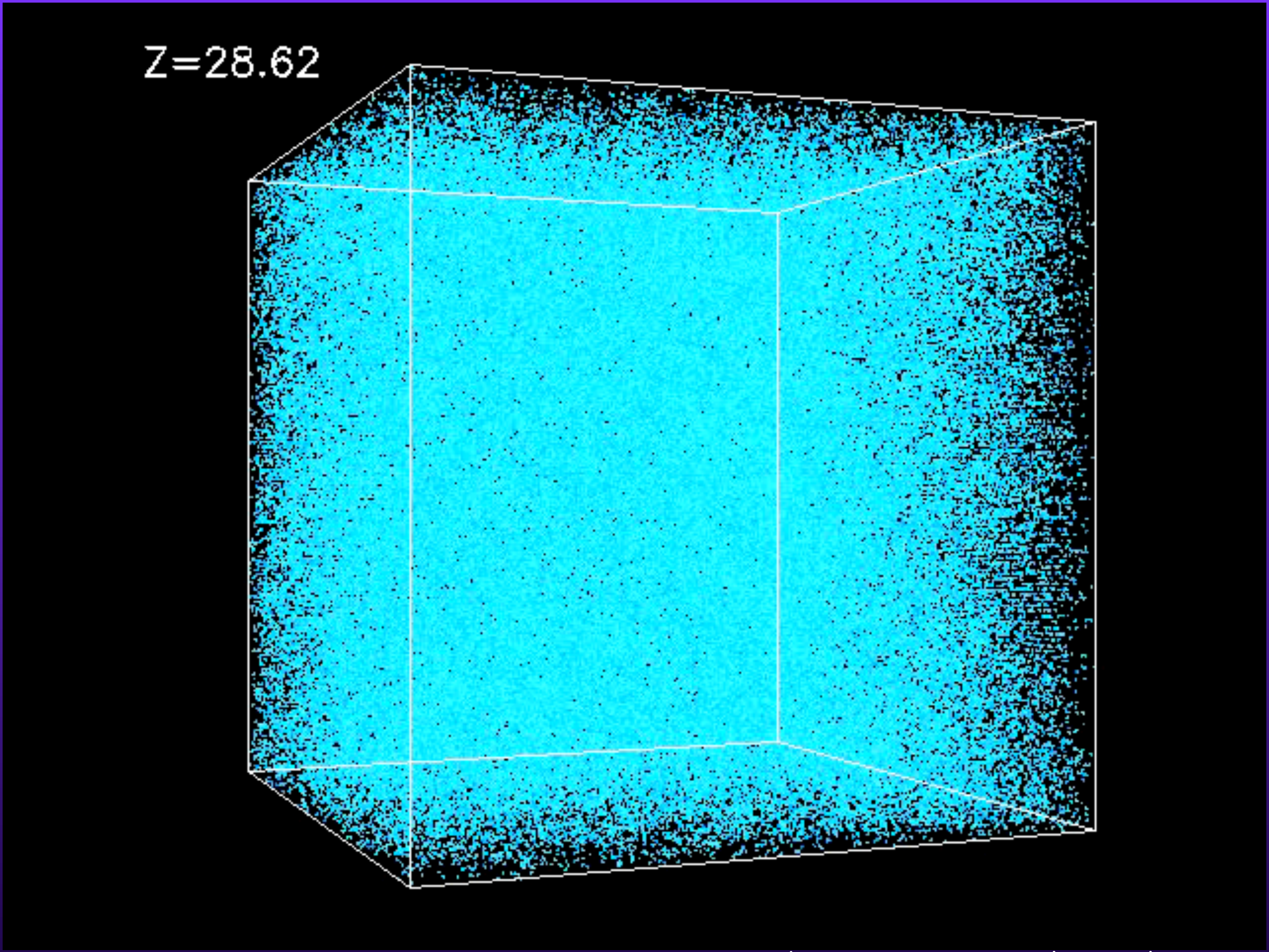
The Star Formation History of the Universe

~10 billion years ago



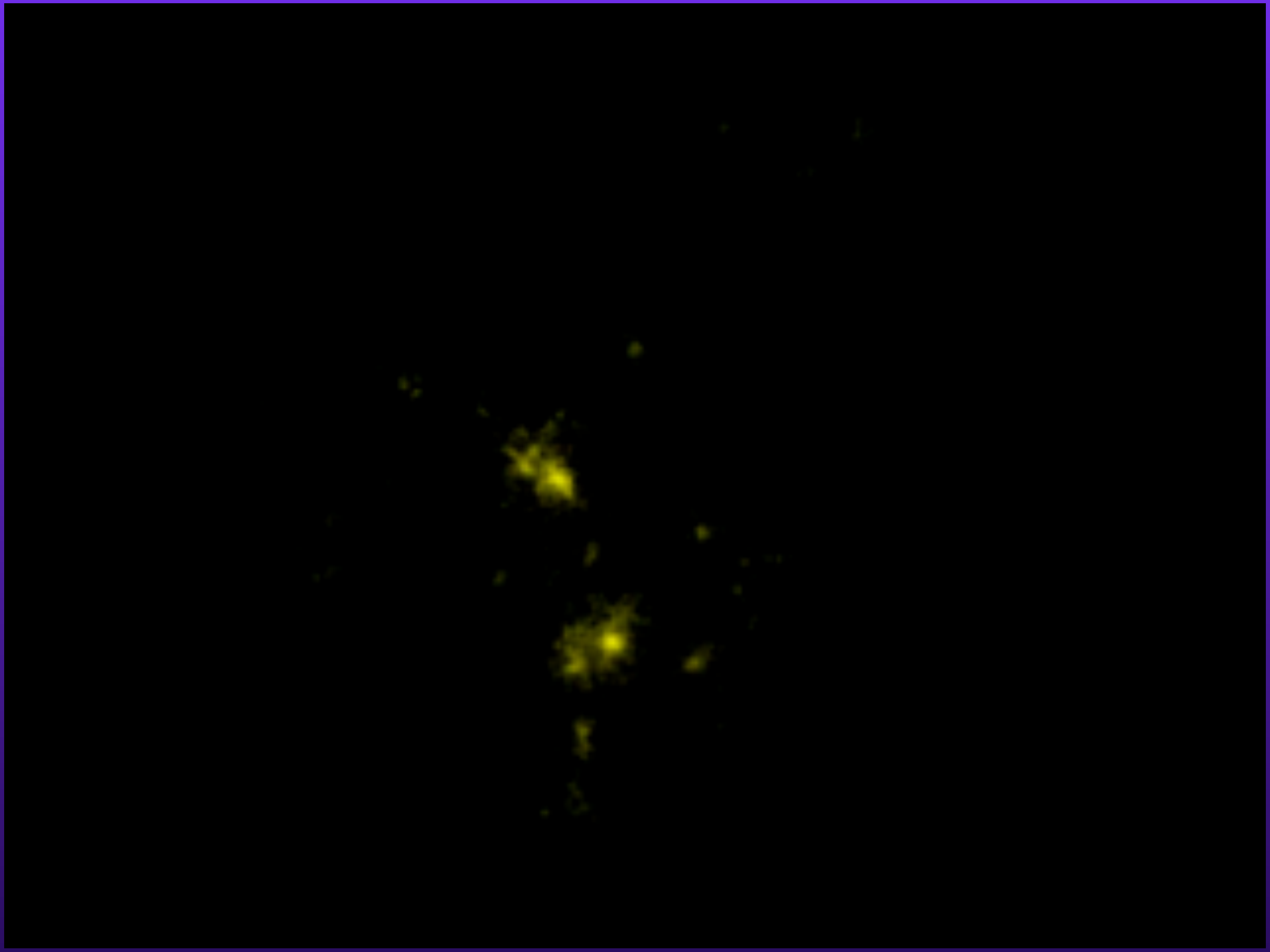
Today…





U. Chicago Computational Cosmology

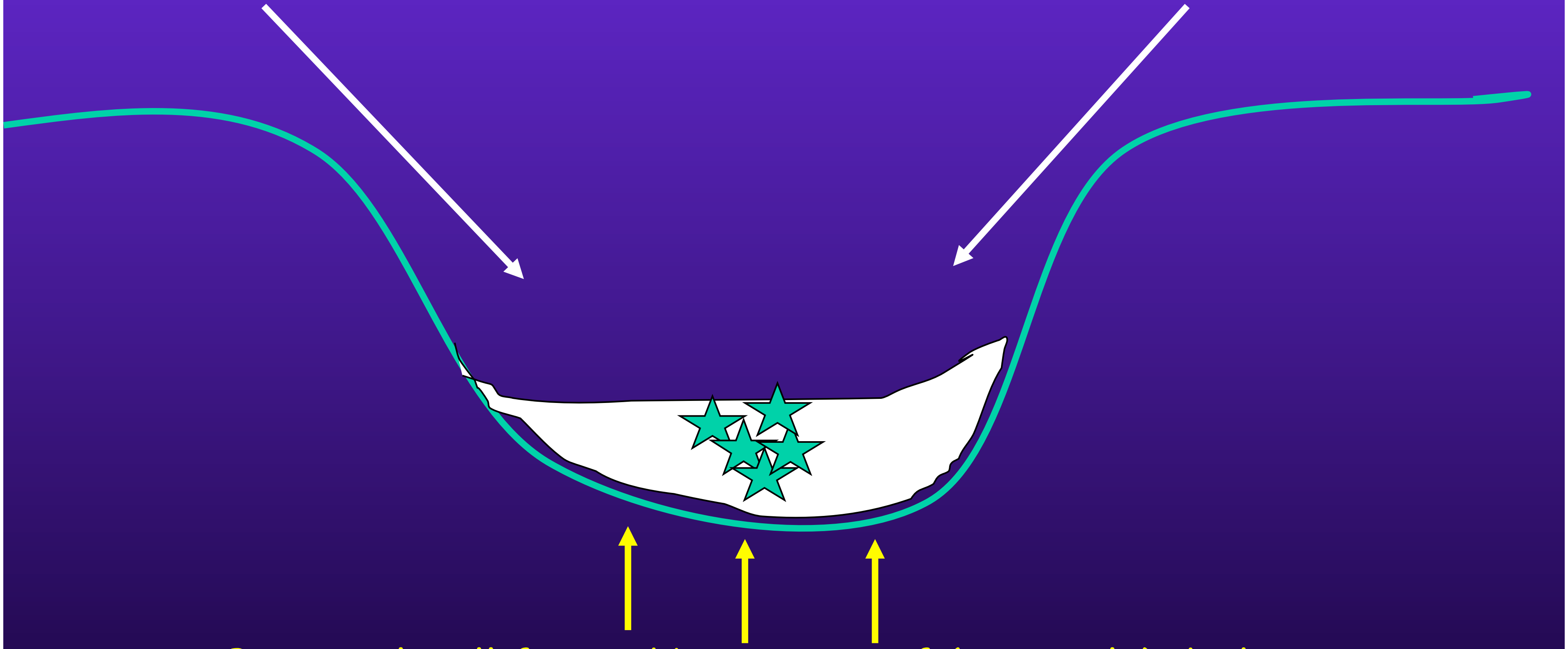
Growing Structure by Gravity



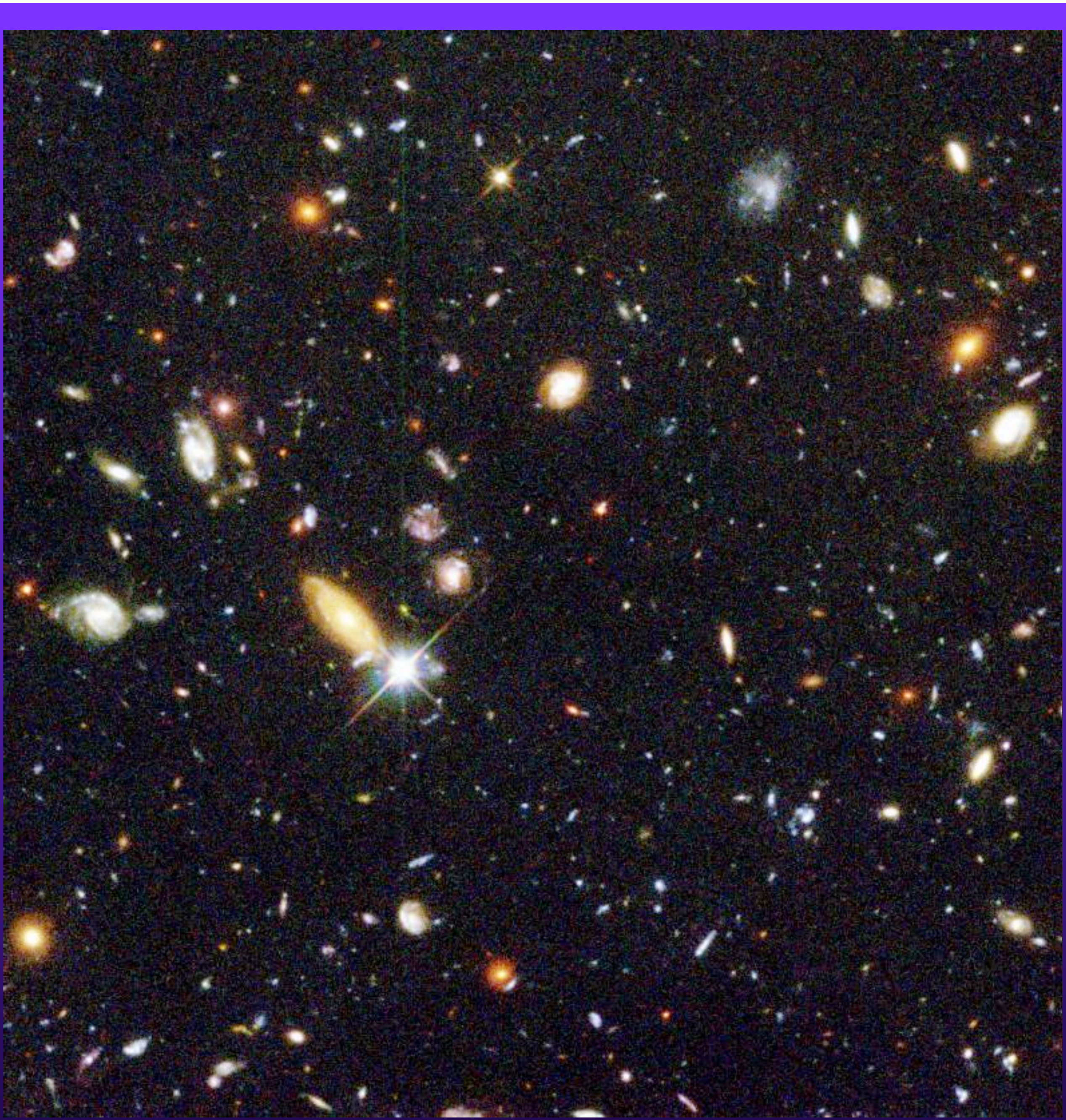
Simulation: The VIRGO Consortium

"Recipe" for Galaxy Formation

- Dark matter (~85% of total mass)
- Normal matter (~15% of mass)
- gas cooling (further collapse of gas)
- energy input via star formation, supernova explosions, black hole accretion ("Feedback")

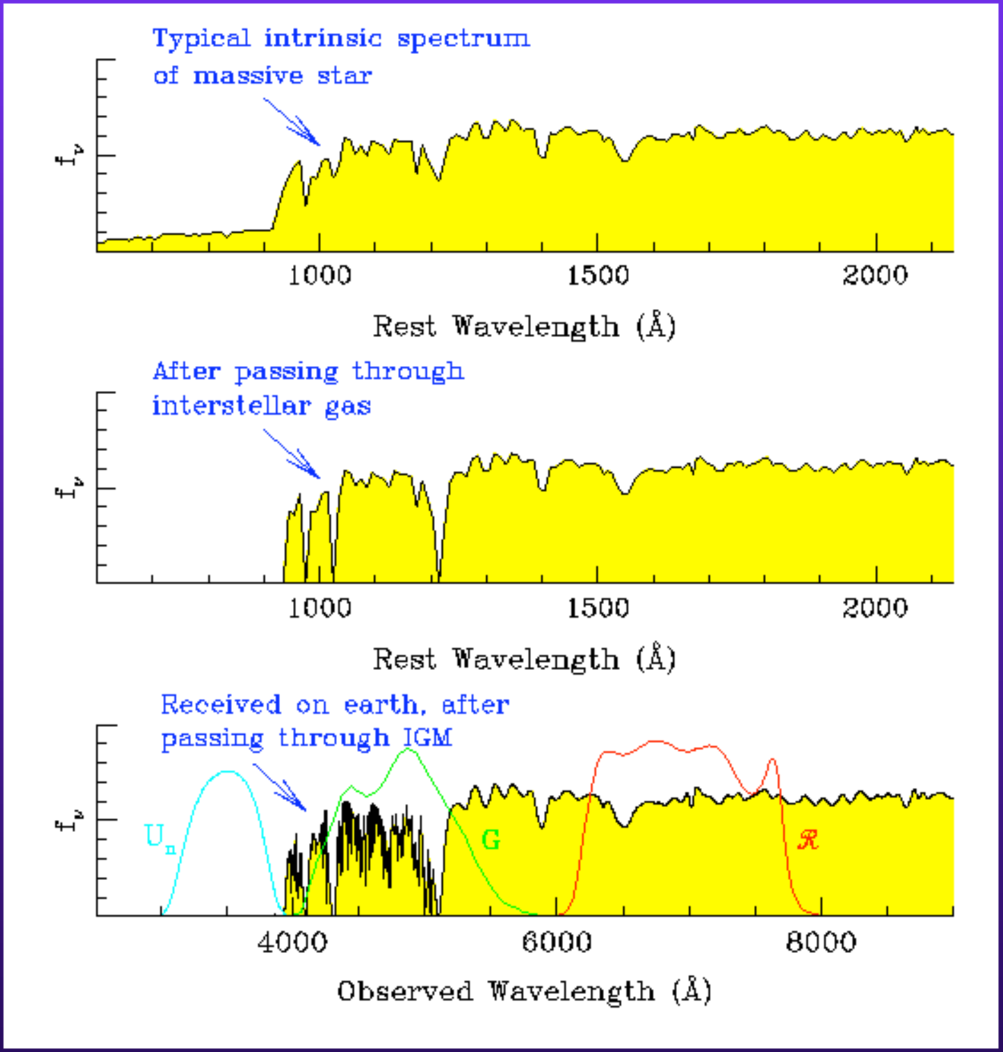


Potential well formed by gravity of (primarily) dark matter



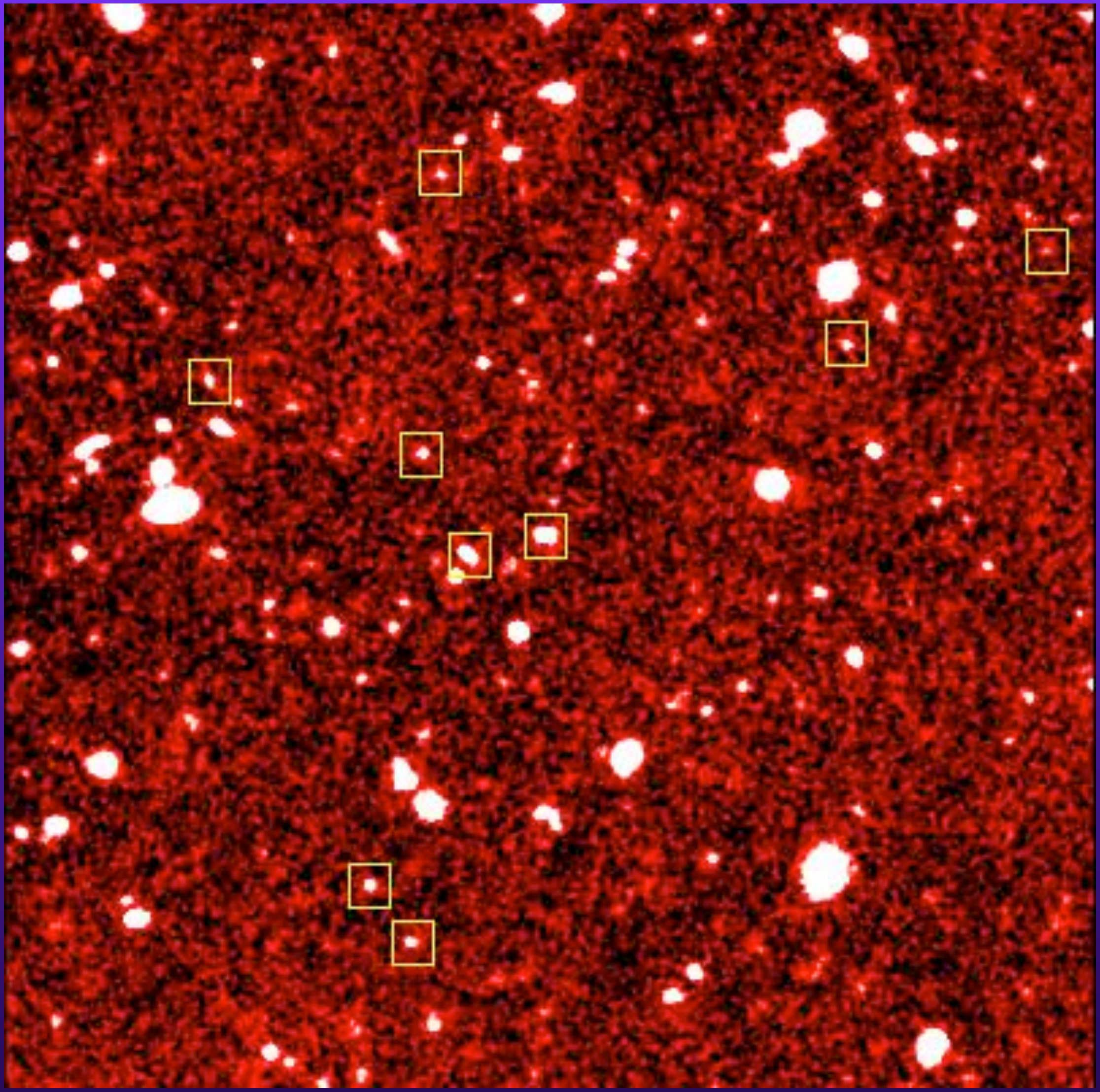
Hubble Deep Field, 1996

Isolating Slices in Cosmic Time

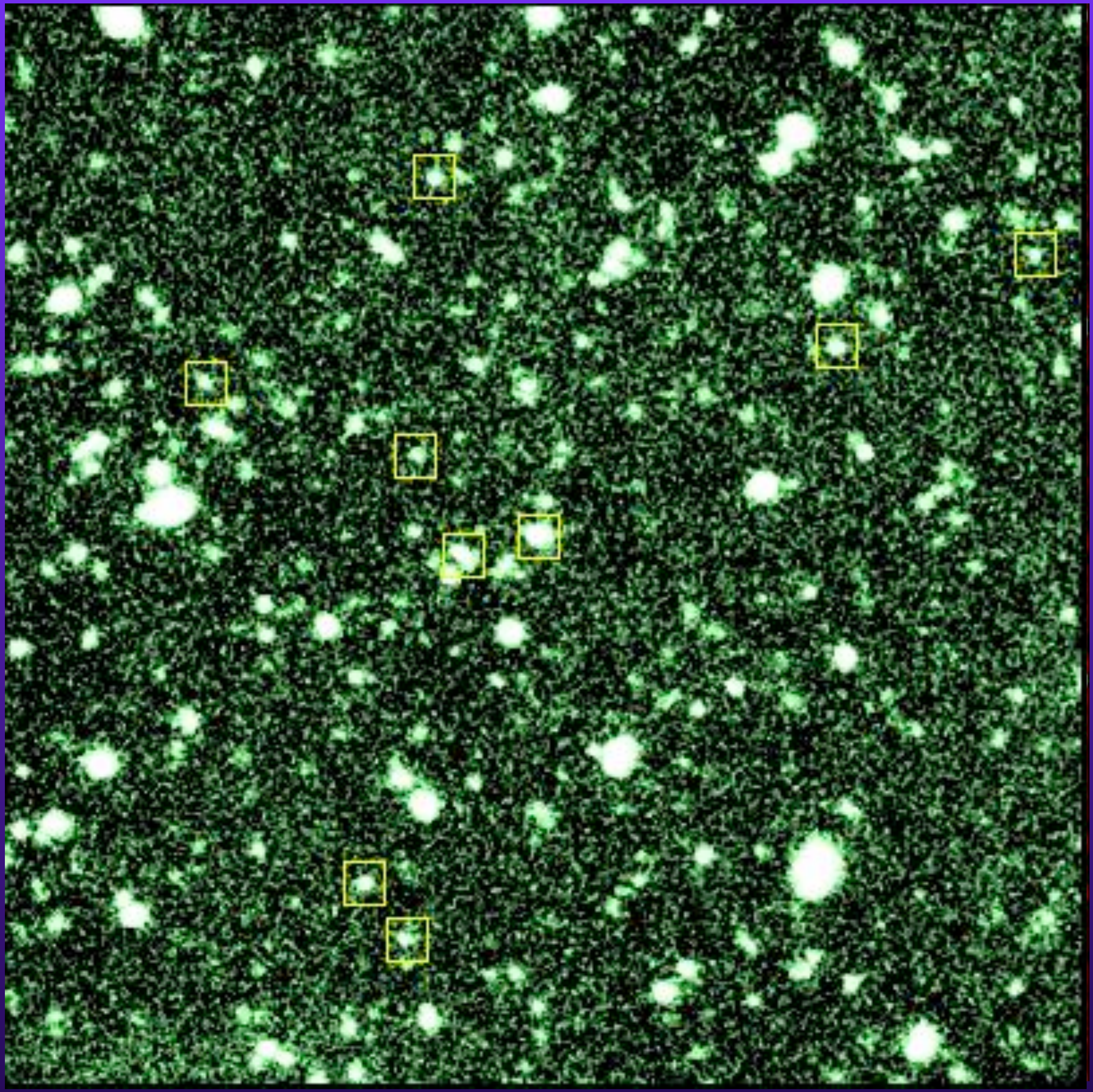


Perhaps simplest means is taking advantage of the known properties of hydrogen illuminated by UV radiation from young stars…

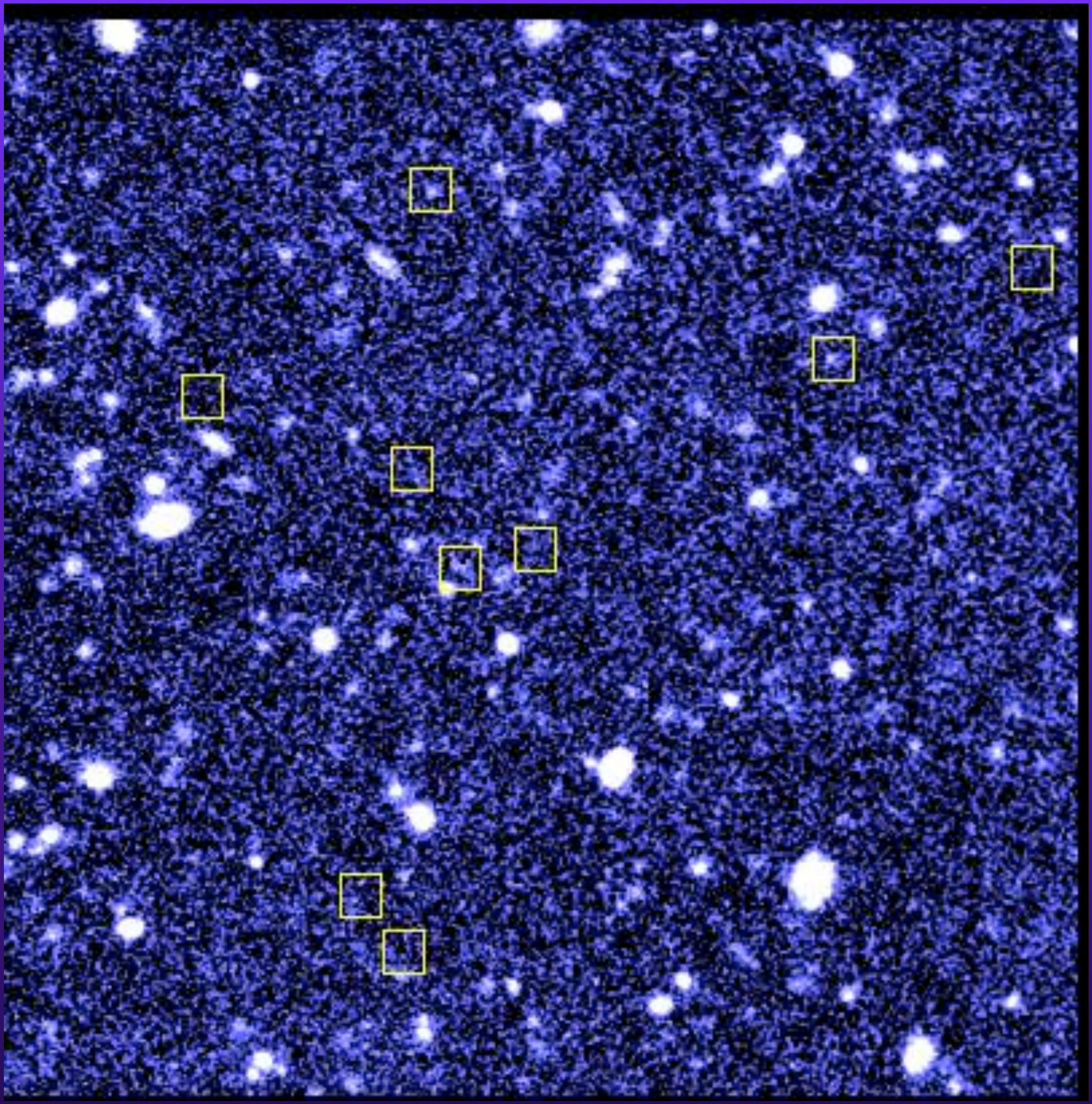
" Drop-Outs": The Simplest Cosmic Filter



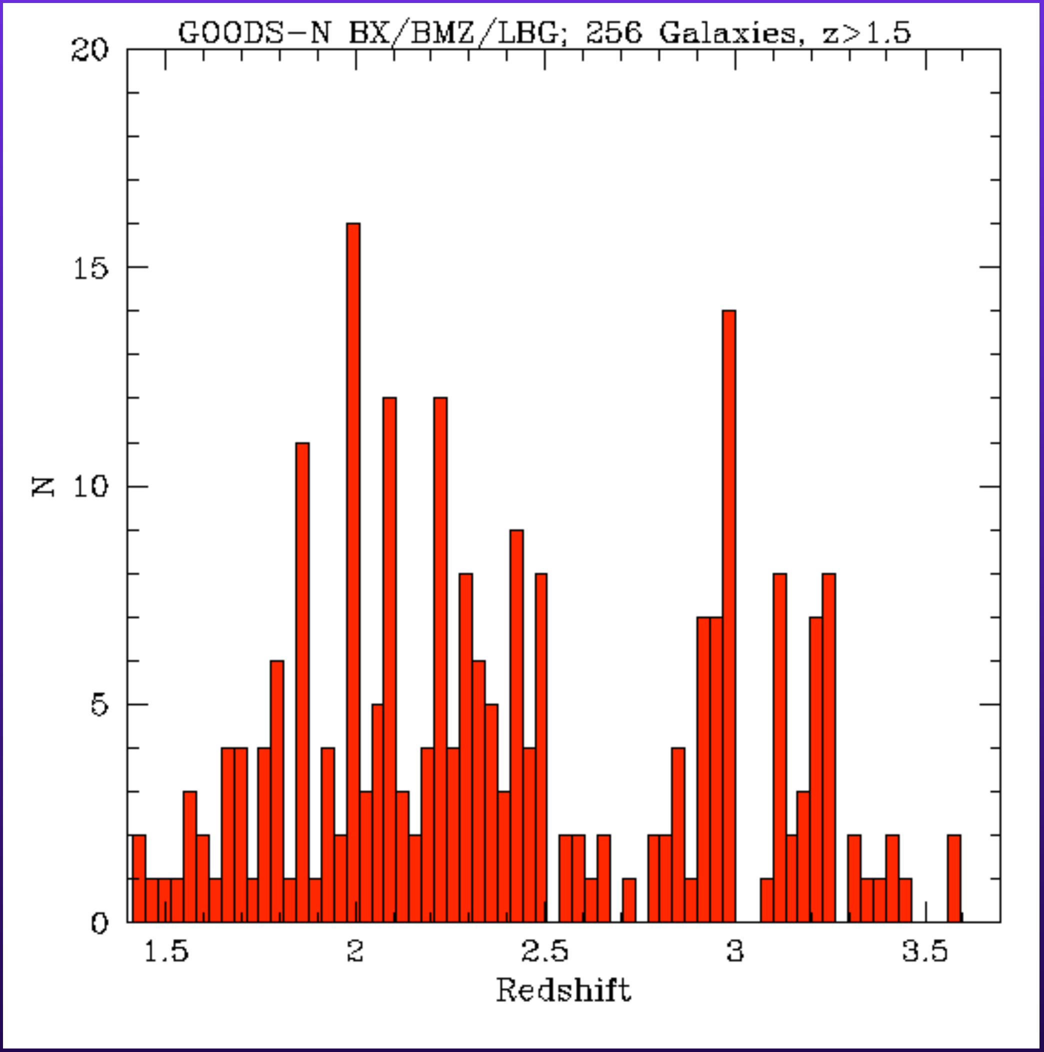
“ Drop-Outs”: The Simplest Cosmic Filter



" Drop-Outs": The Simplest Cosmic Filter



Spectroscopy



- spectroscopy of distant galaxies is very difficult and requires the largest ground-based telescopes!

Magellan Observatory

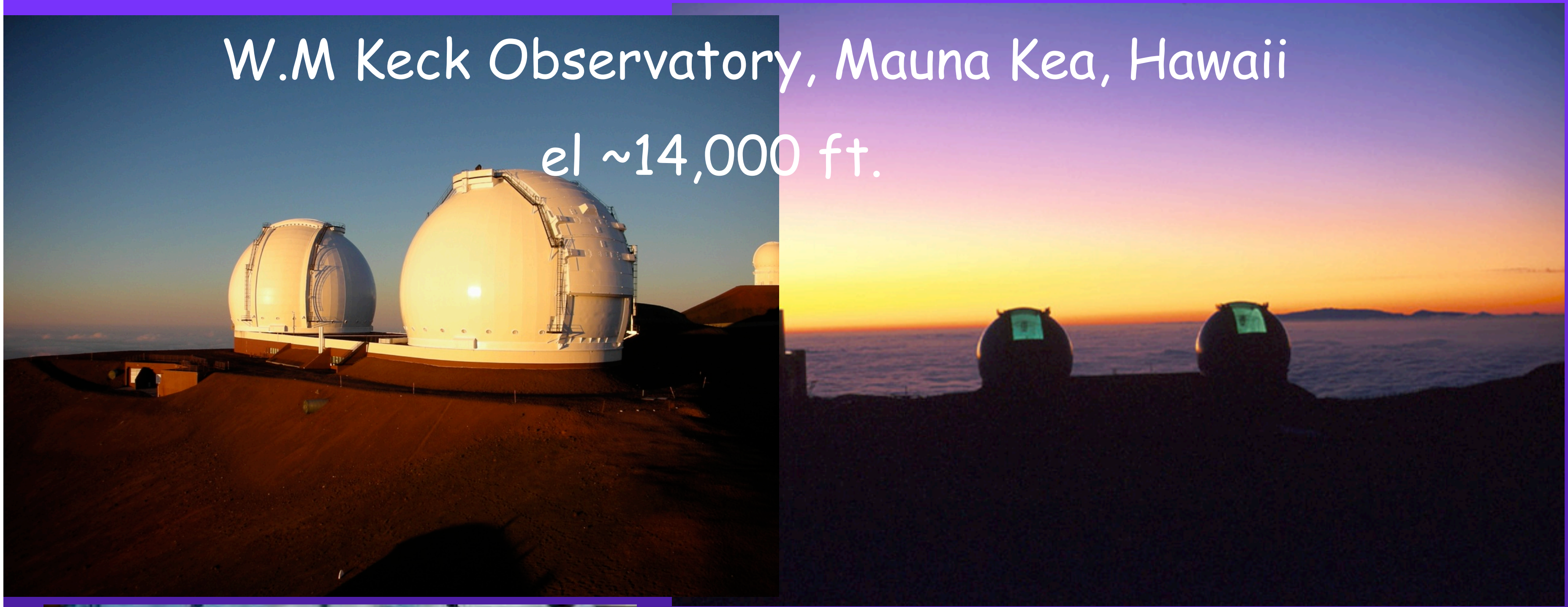
Cerro Las Campanas, Chile
el ~ 7500 ft.

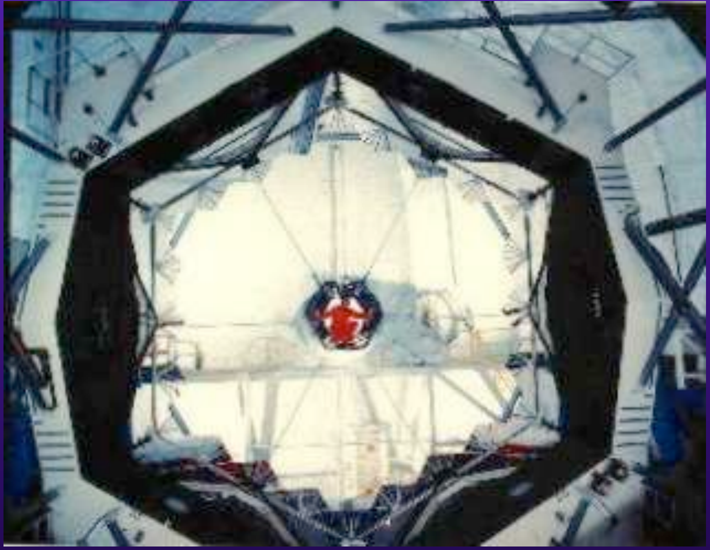
2 telescopes, each 6.5m (~21 ft) in diameter

- U. Michigan
- Harvard/Smithsonian
- MIT
- Carnegie Institution
- U. Arizona

W.M Keck Observatory, Mauna Kea, Hawaii

el ~14,000 ft.

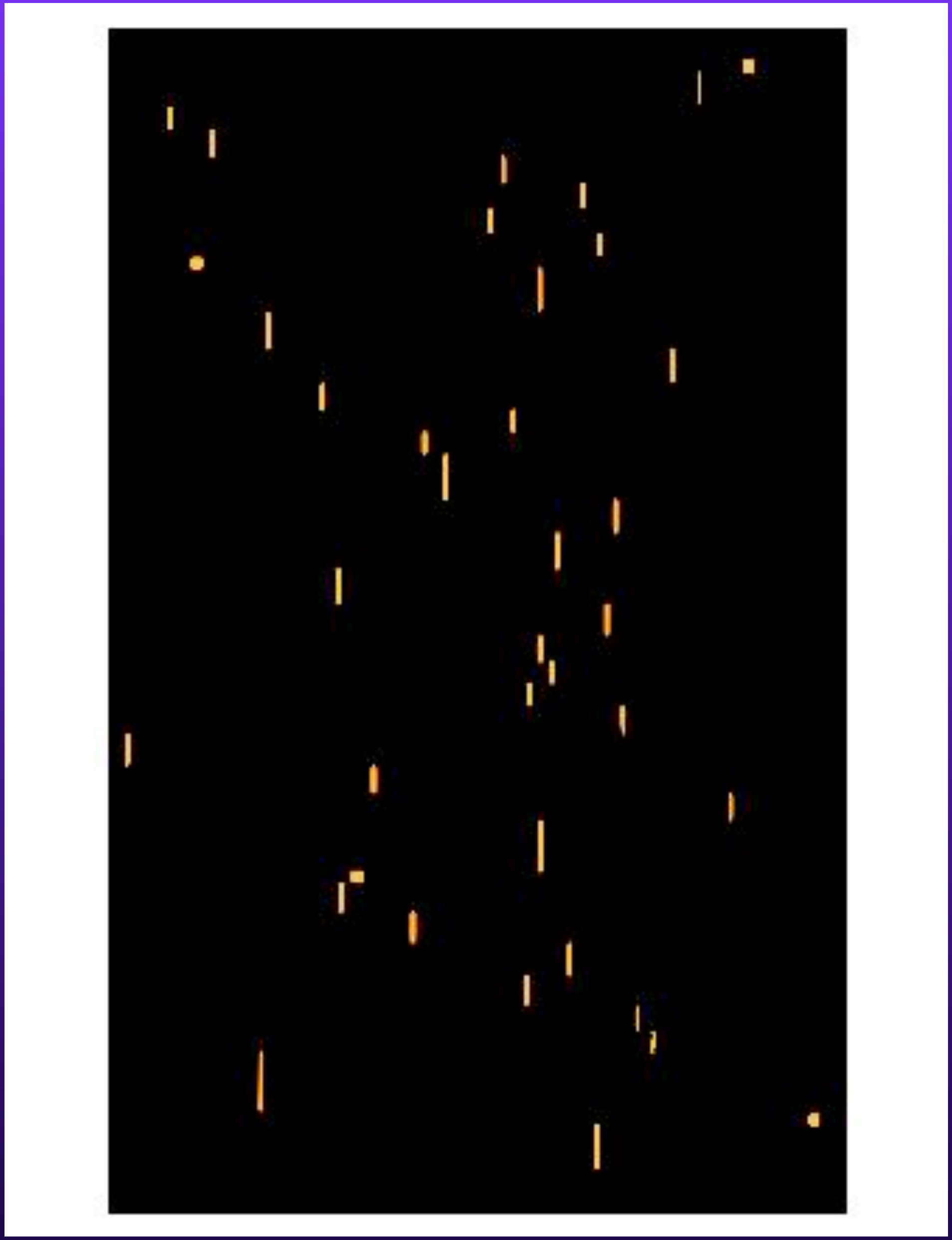




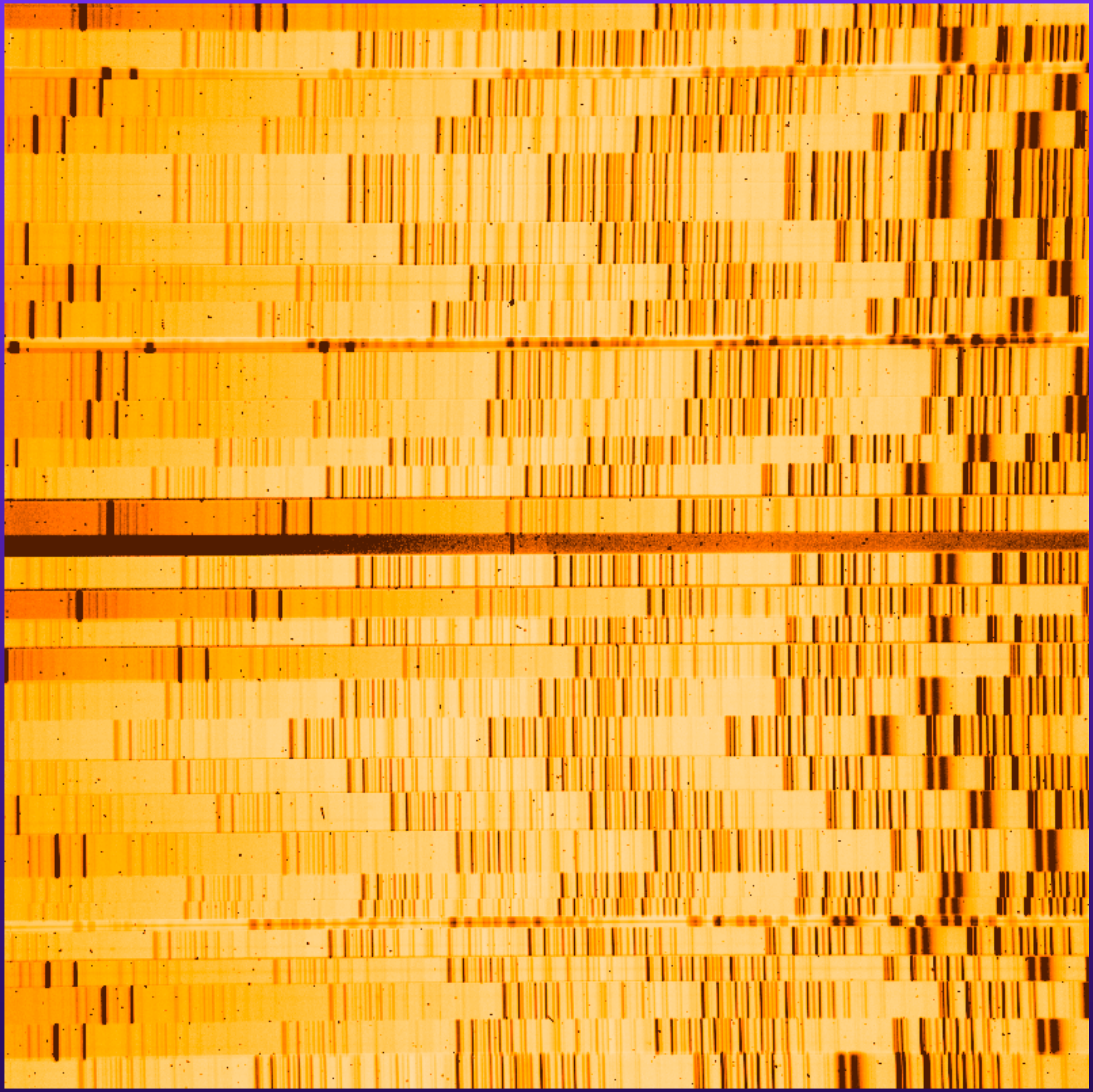
2 10m (~33 ft) diameter telescopes

- Caltech
- U. California
- NASA

Spectroscopy: Key to Understanding Early Galaxies



Multi-Object Spectroscopy



Wavelength →

The long exposures necessary to obtain spectra of extremely faint objects are made more “palatable” because we can do many objects simultaneously

“Raw” data look like very good spectra of the night sky.

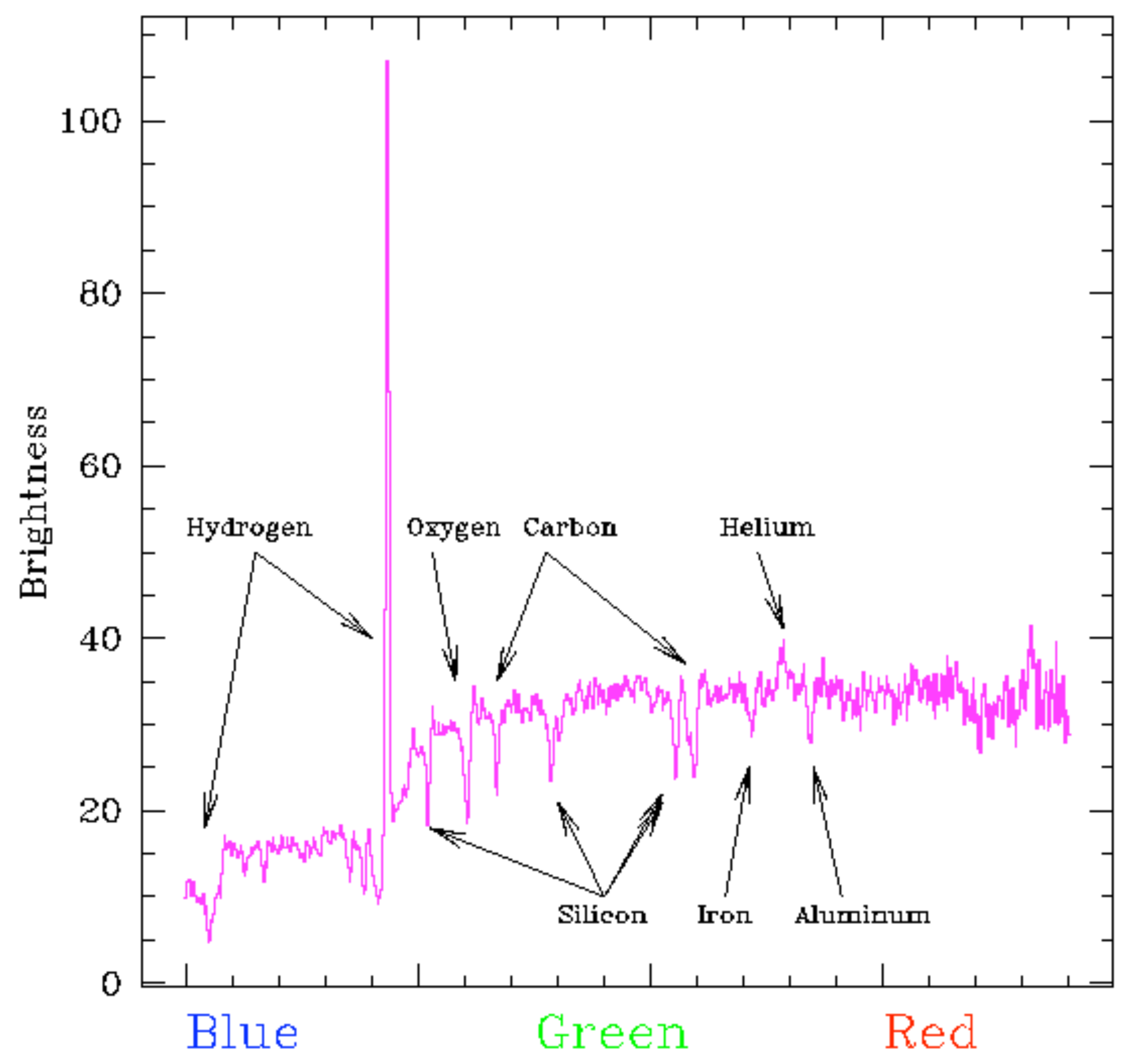
Multi-Object Spectroscopy

Wavelength →

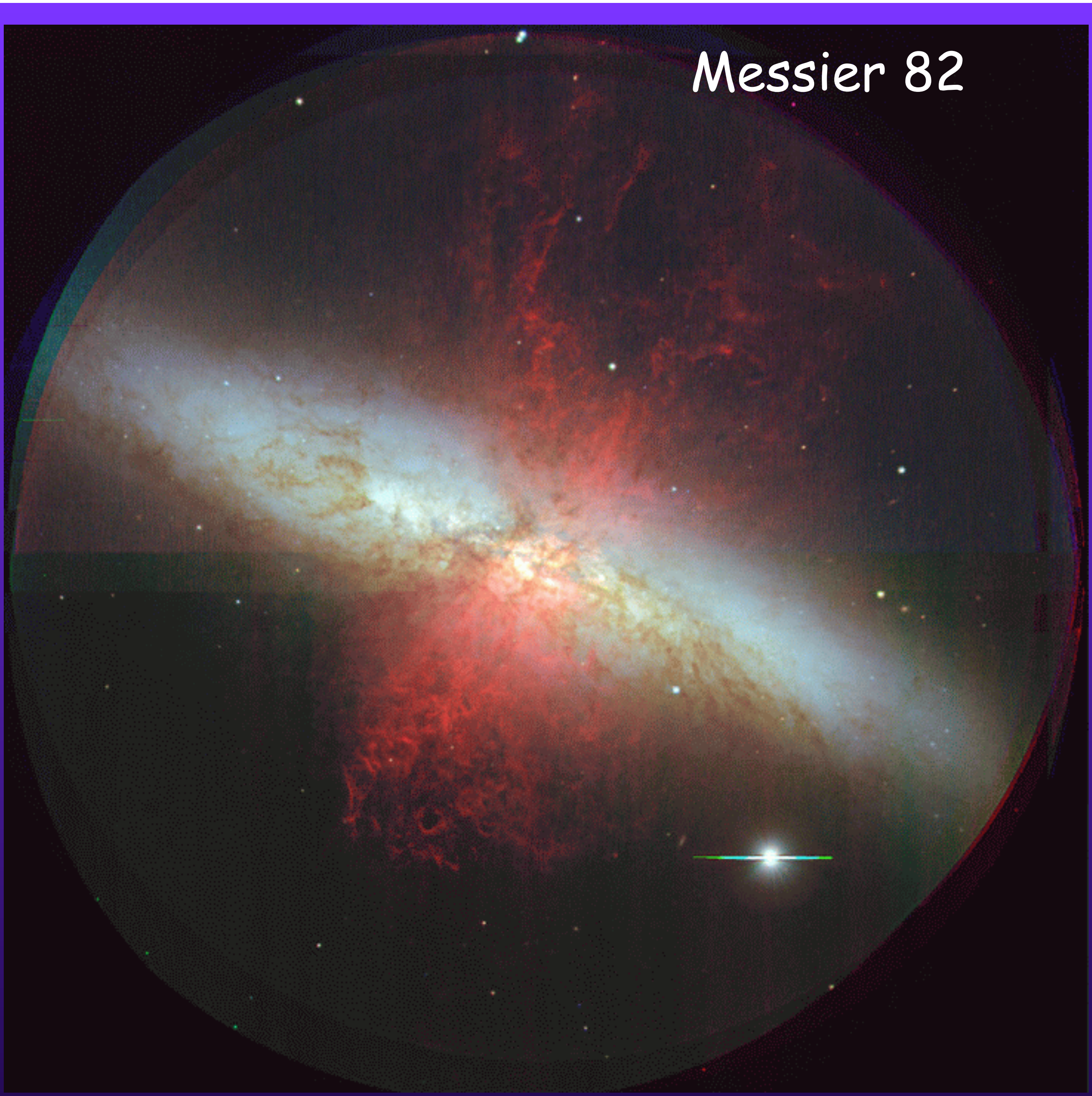
The long exposures necessary to obtain spectra of extremely faint objects are made more "palatable" because we can do many objects simultaneously

Background-subtracted data reveal faint objects

A spectrum is worth much more than 1000 words…



- Precise Distances
- Chemistry
- Gas and stellar motions
- Stellar content
- Mass

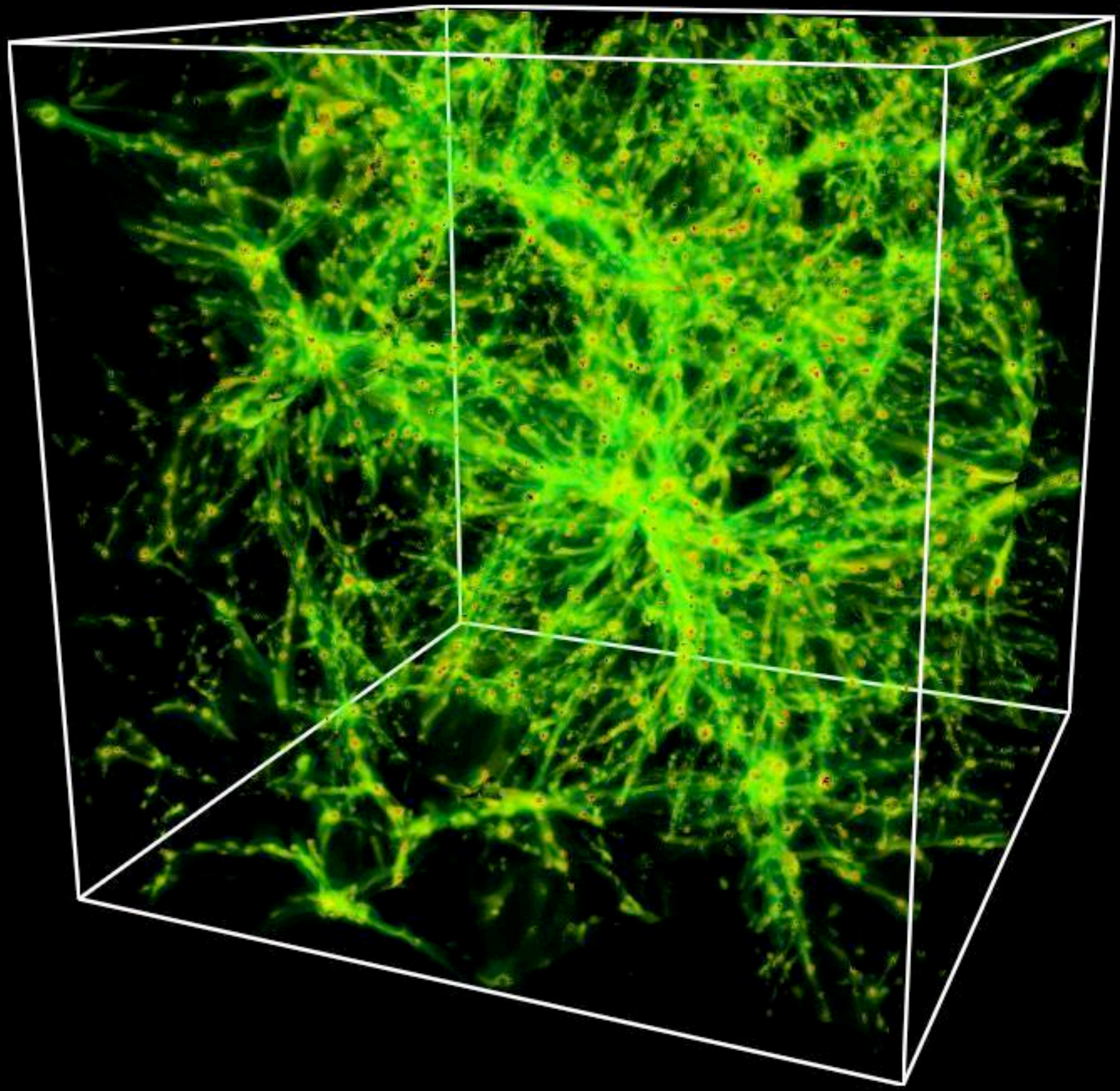


Messier 82

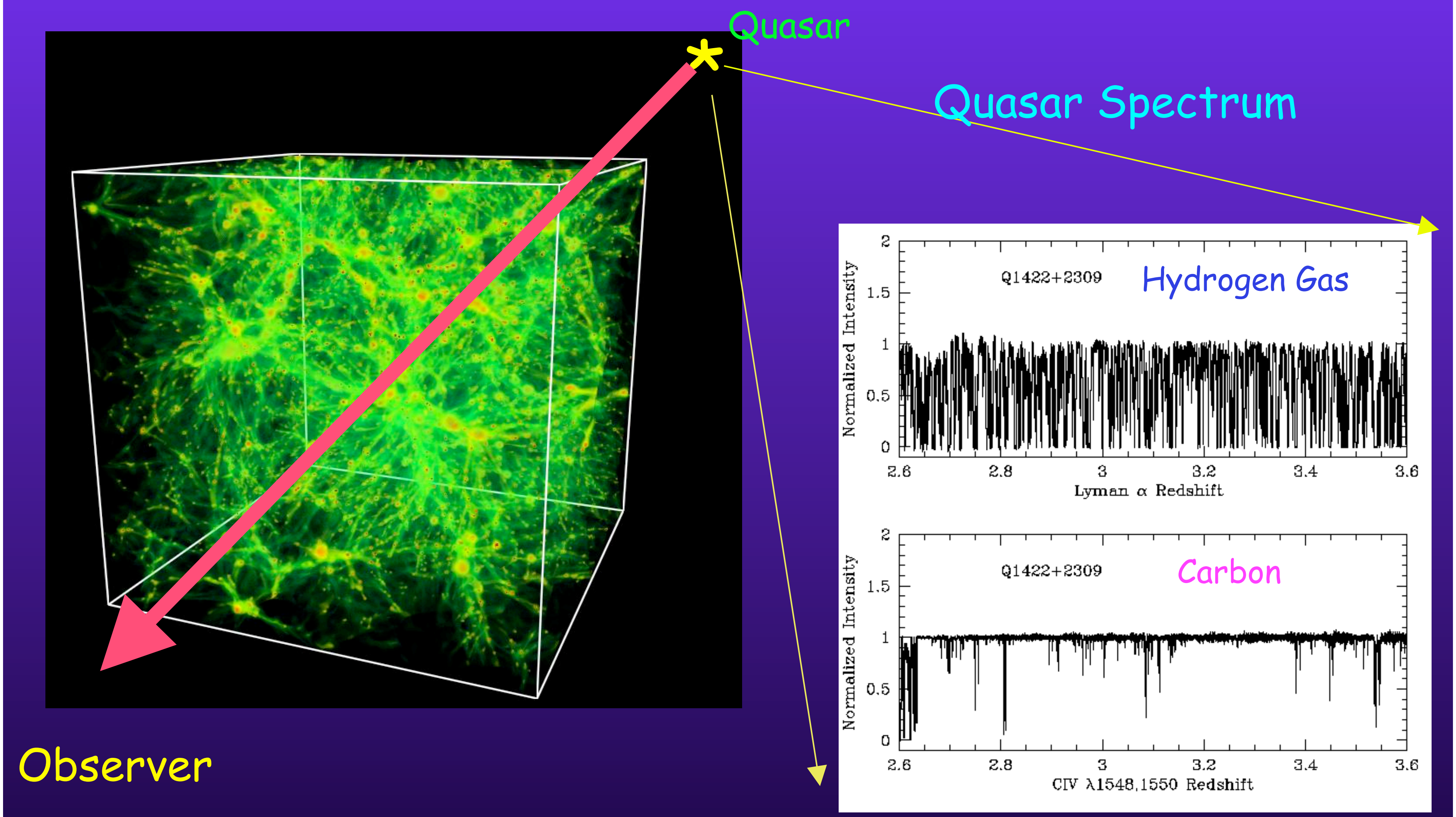
Supernova Remnant
"Cassiopeia A"

(this one is from 1572, noticed by Kepler)

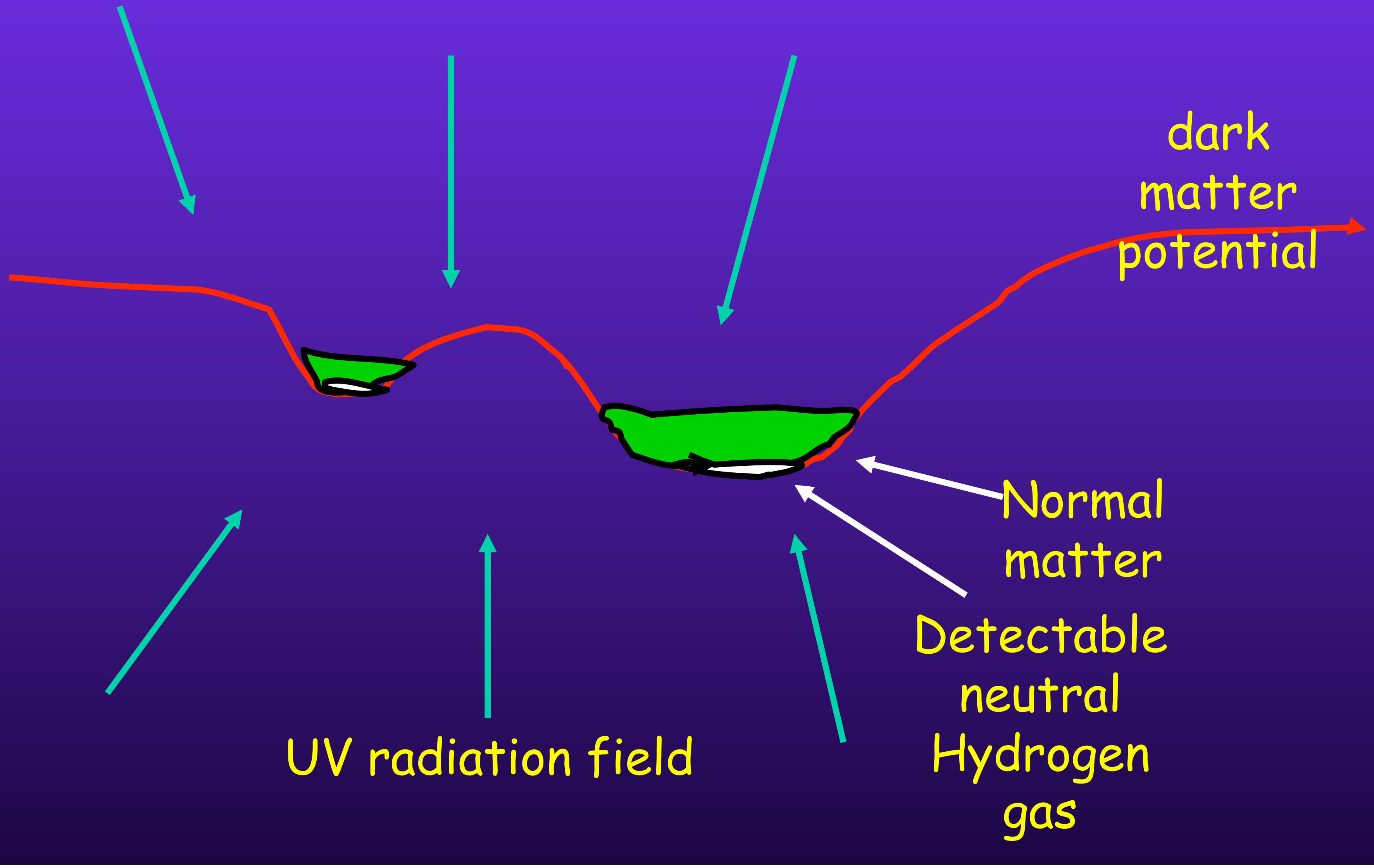
The Diffuse Intergalactic Medium: A new laboratory for studying galaxy formation

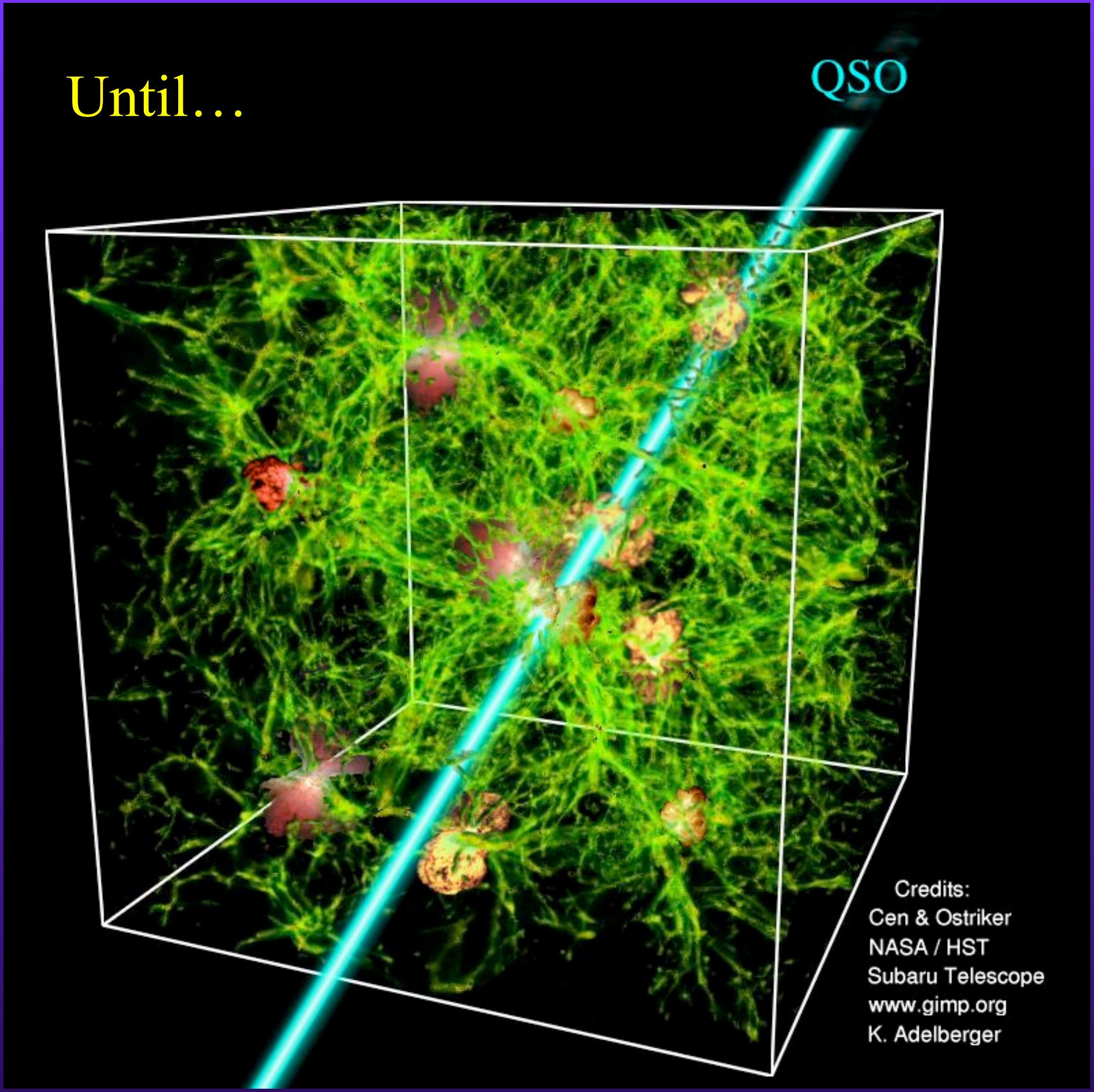


Probing The Intergalactic Medium Using Quasar Absorption Lines



The Intergalactic Medium: Generally a Boring Place…

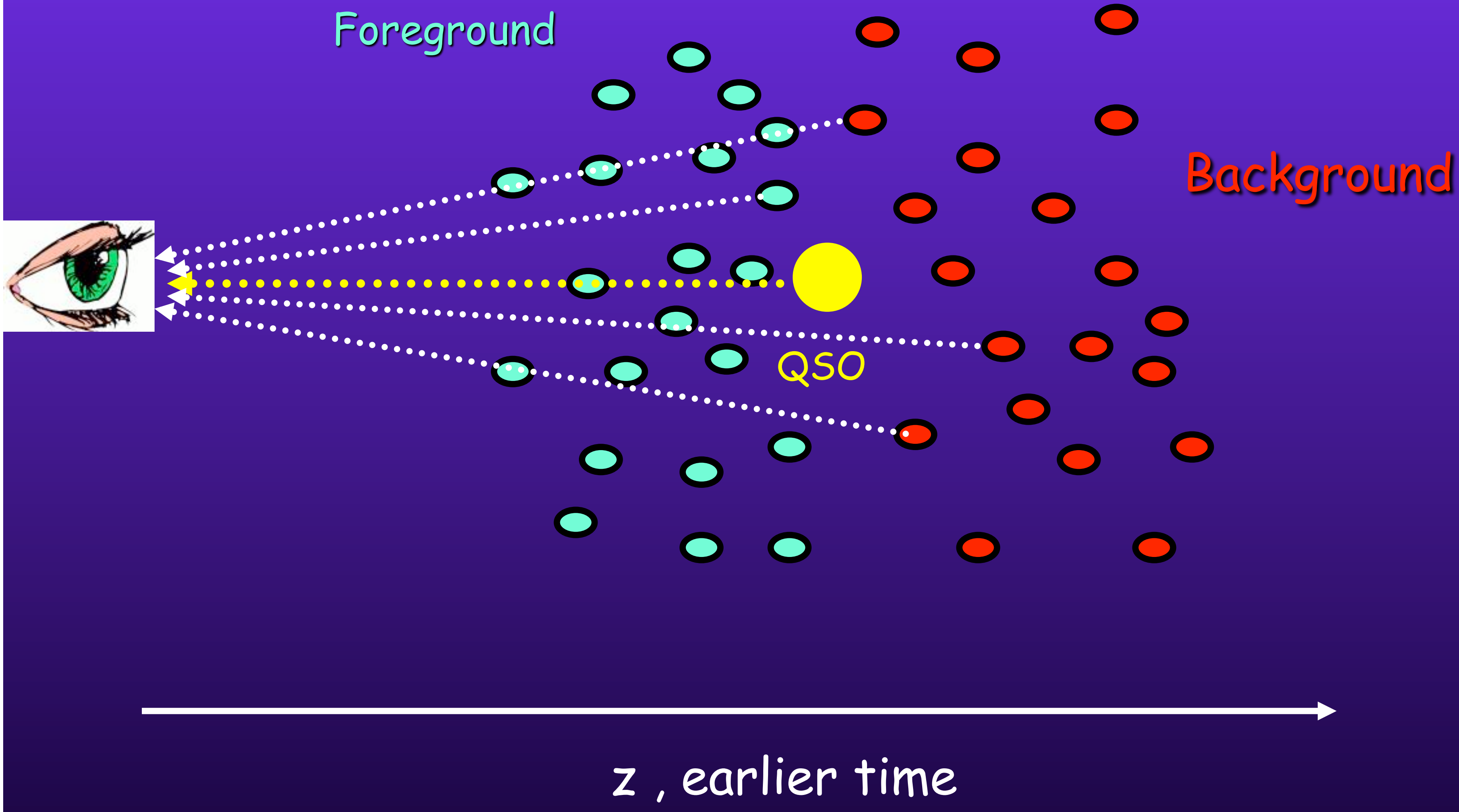




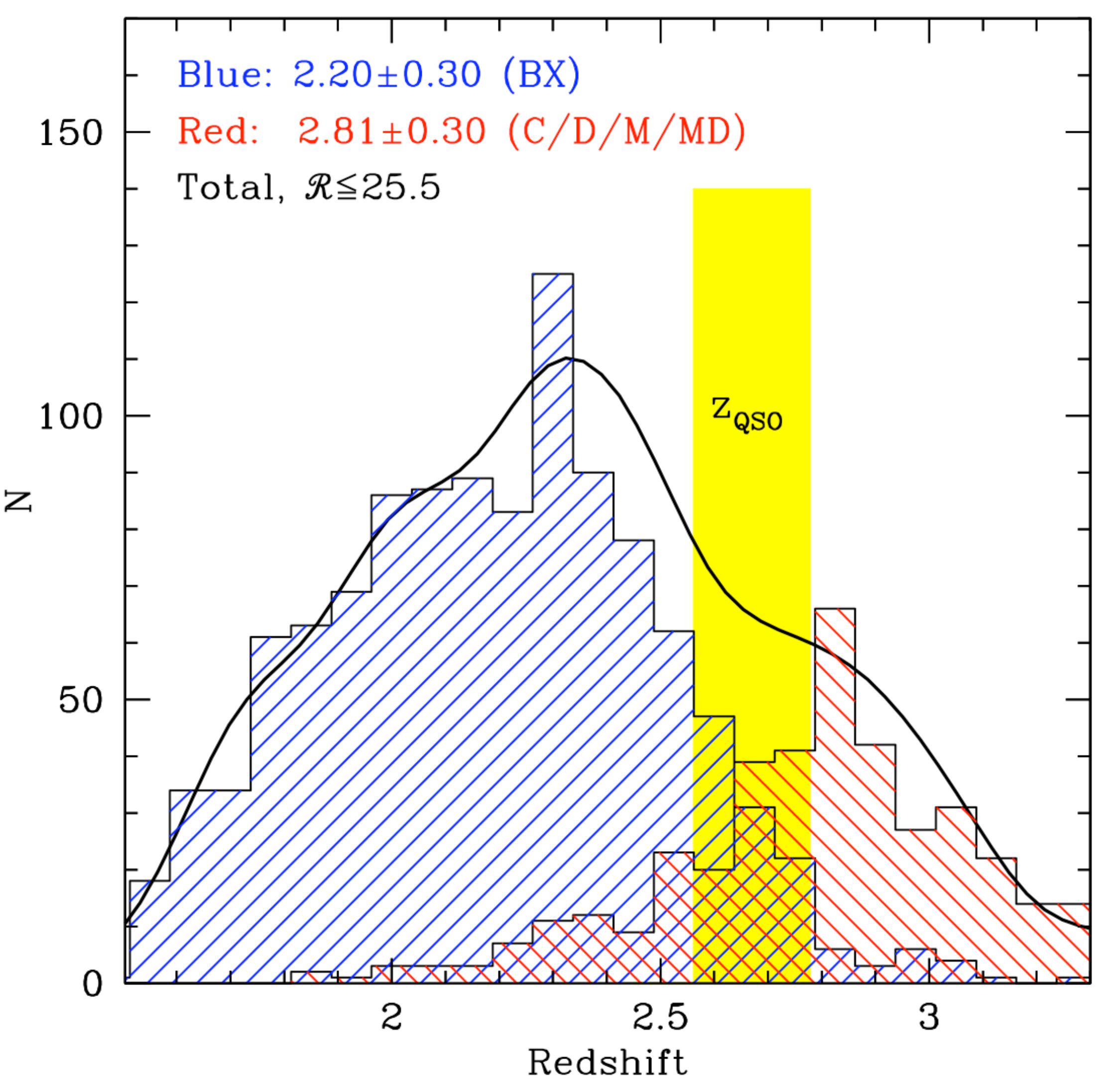
Credits:
Cen & Ostriker
NASA / HST
Subaru Telescope
www.gimp.org
K. Adelberger

“Artist’s conception” of explosive galaxy formation, embedded in the otherwise sleepy intergalactic medium

Densely Sampling the Universe

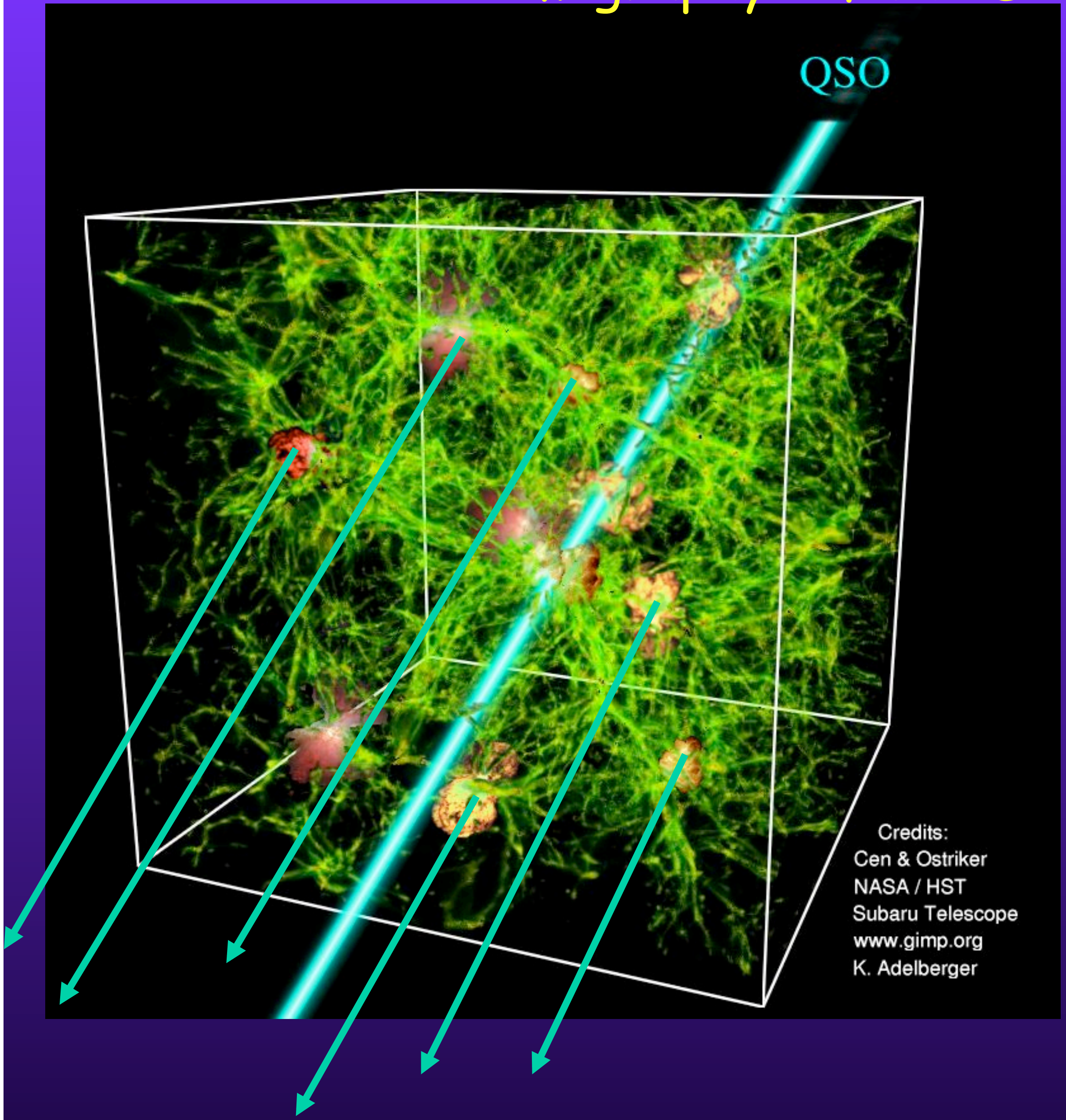


Drilling Core Samples of the Young Universe



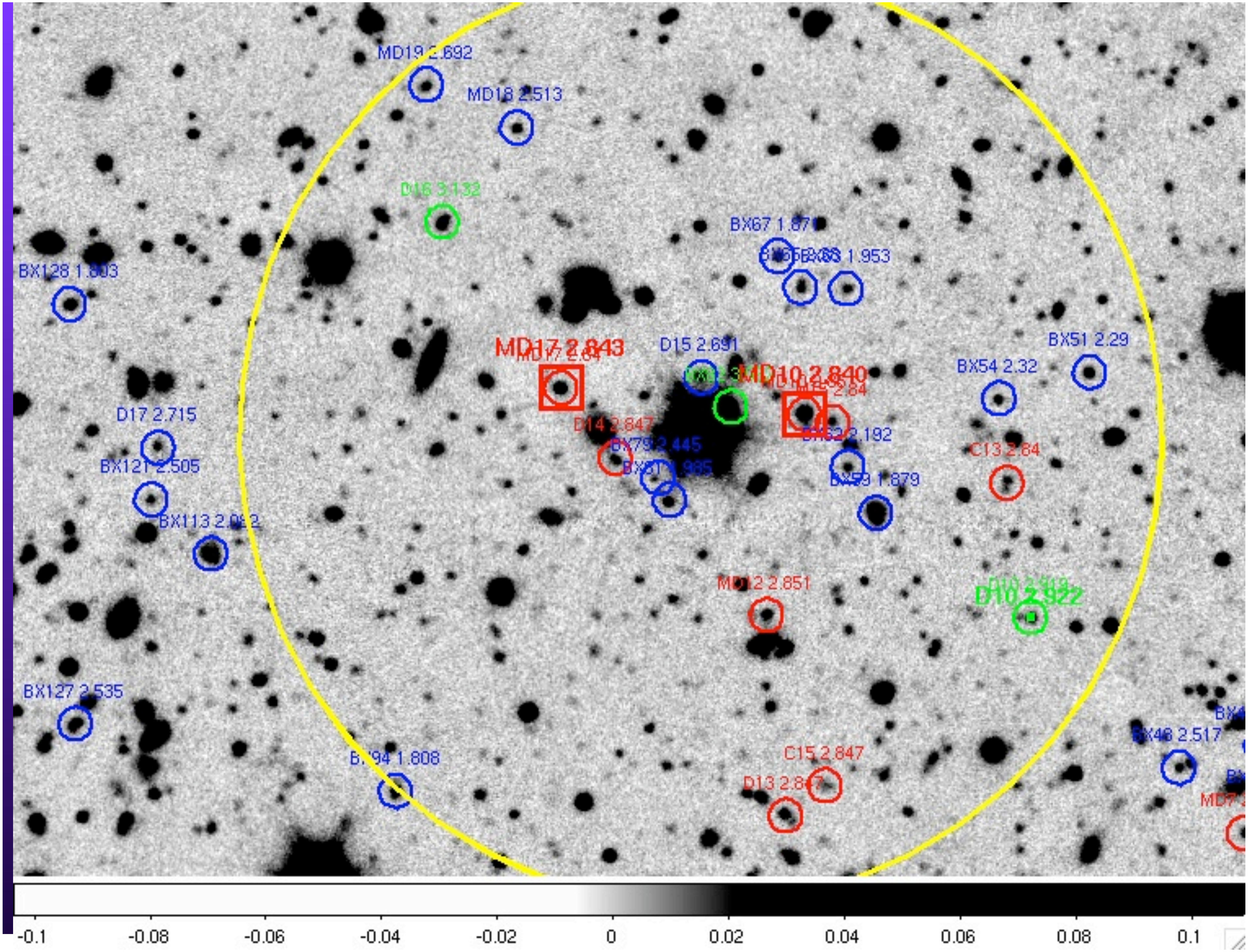
Relative surface density vs. redshift

“Tomography” of the Distant Universe

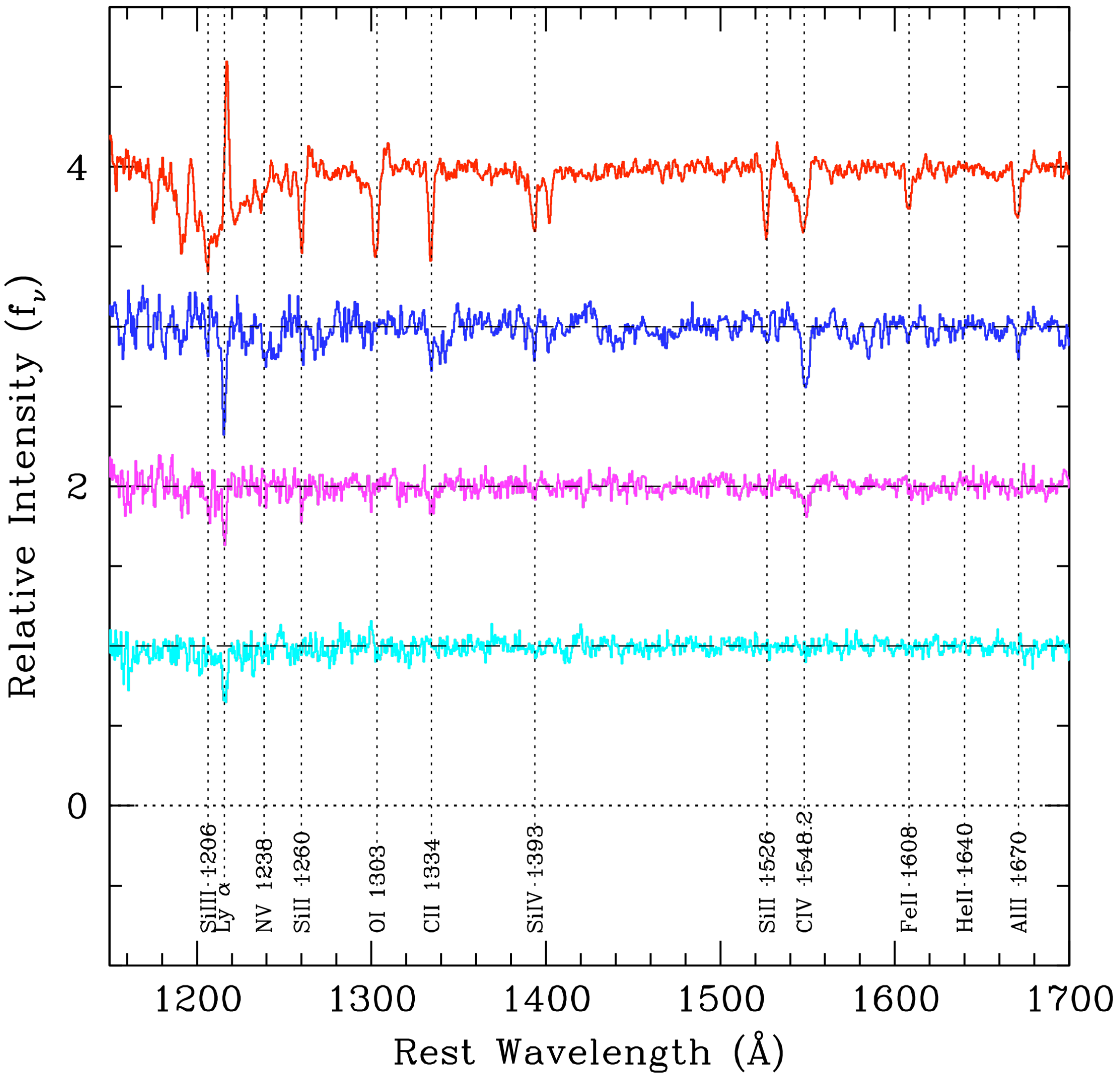


Credits:
Cen & Ostriker
NASA / HST
Subaru Telescope
www.gimp.org
K. Adelberger

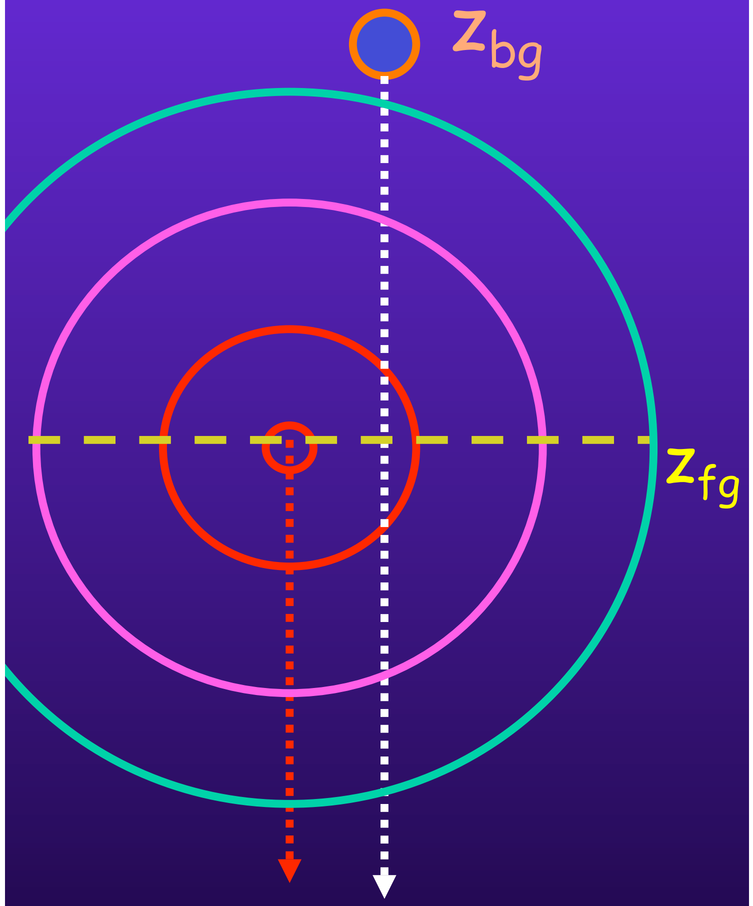
Idea is to map the whole “web” of structure when the universe was young, during the peak of galaxy formation


MD19 2.692
MD18 2.513
D16 3.132
BX67 1.871
1.953
BX128 1.803
MD17 2.843
D15 2.691
MD10 2.840
2.84
BX51 2.29
BX54 2.32
D17 2.715
D14 2.847
BX79 2.445
1.985
2.192
C13 2.84
BX121 2.505
1.879
BX113 2.0
MD12 2.851
D10 2.922
BX127 2.535
BX48 2.517
C15 2.847
1.808
D13 2.8
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1

Galaxy Pair Composite Spectra



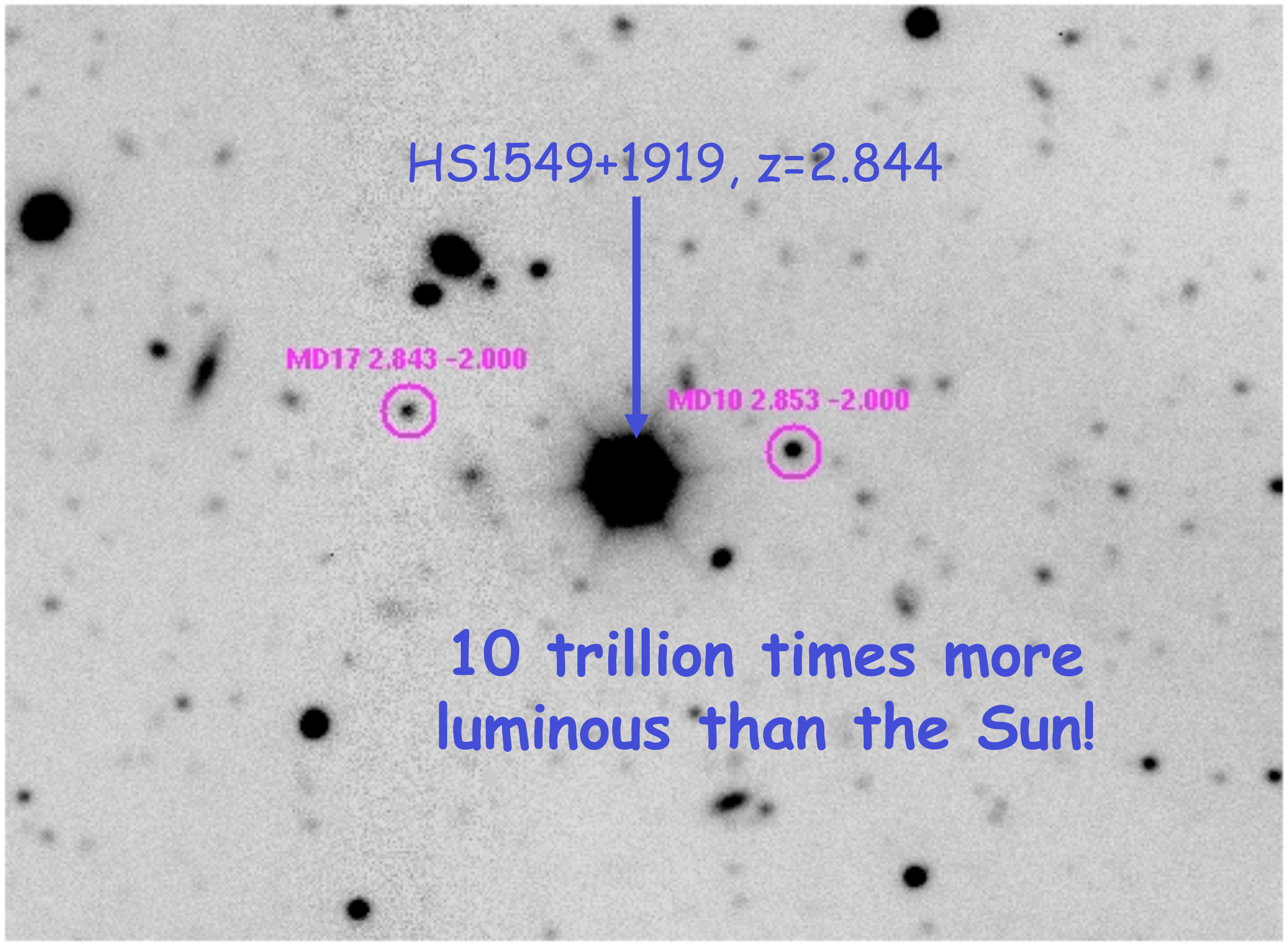
- 50 pairs 1-5″ (<d>=30 kpc)
- 190 pairs 5-10″ (<d>=70 kpc)
- 305 pairs 10-15″ (<d>=100 kpc)



A Physical Picture of Young Galaxies

- Gas blown out by supernova explosions at speeds of > 600 km/sec
- Shock wave heats gas up to ~10^7 K (or so)
- Blows heavy elements into the intergalactic medium
- Typical extent is ~100 times the apparent (luminous) size of the galaxy
- Most of the metals may be in the IGM, at temperatures too high to be easily detectable.

The Quasar Phase: Luminous cosmic beacons



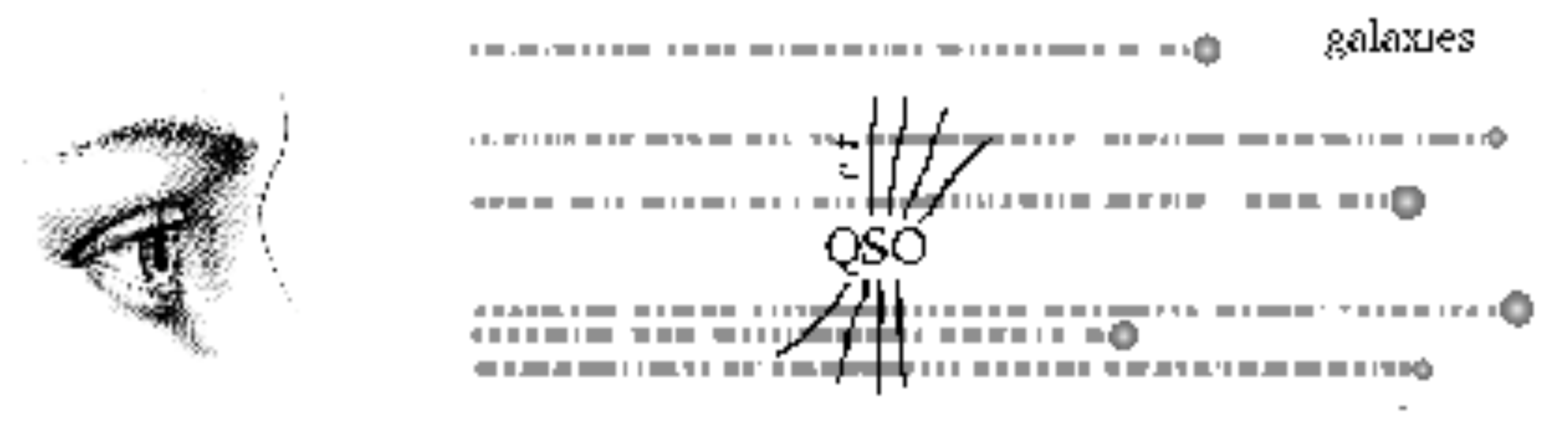
HS1549+1919, z=2.844

10 trillion times more luminous than the Sun!

Black Holes and Galaxy Formation

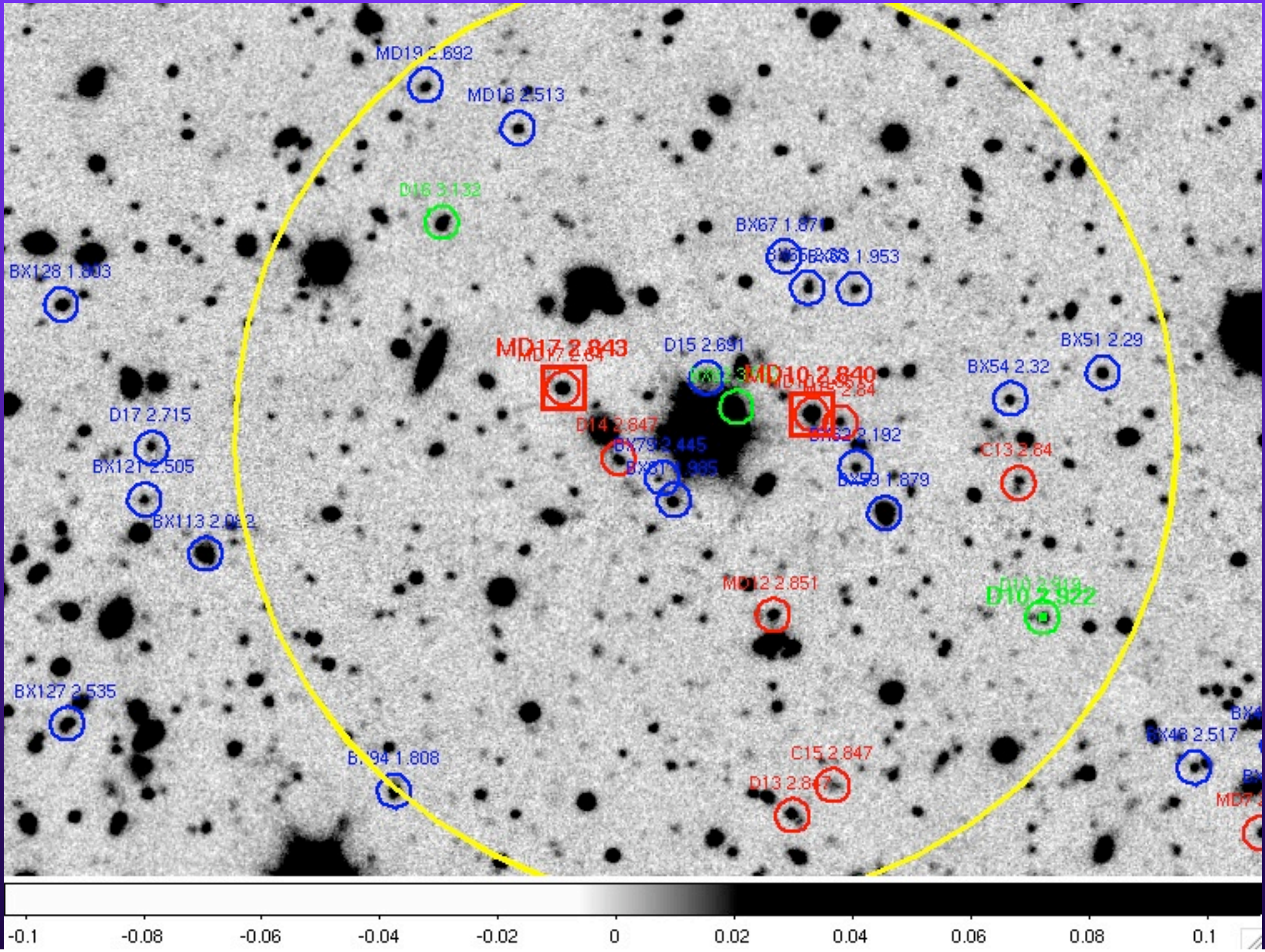
Simulation: Hernquist, Springel, et al

Generally presumed that galaxies and black holes grow together, but process is not yet well understood!

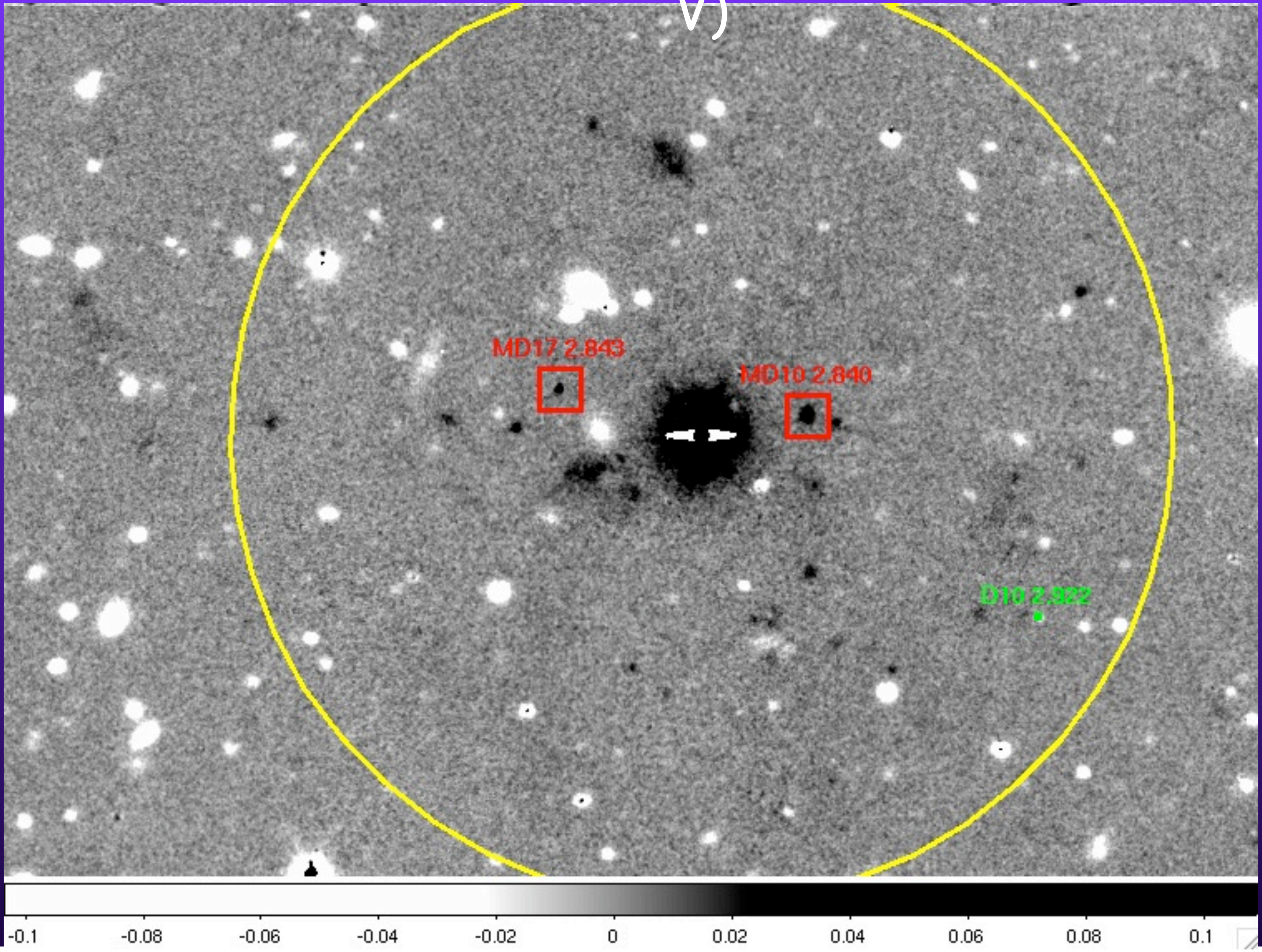


- Observe galaxies both “in front of” and “behind” quasars and use the whole system to explore the intergalactic medium and the energetics of explosive processes in the early universe.

A Quasar "Smokes" the Surrounding ~1 million Lyr



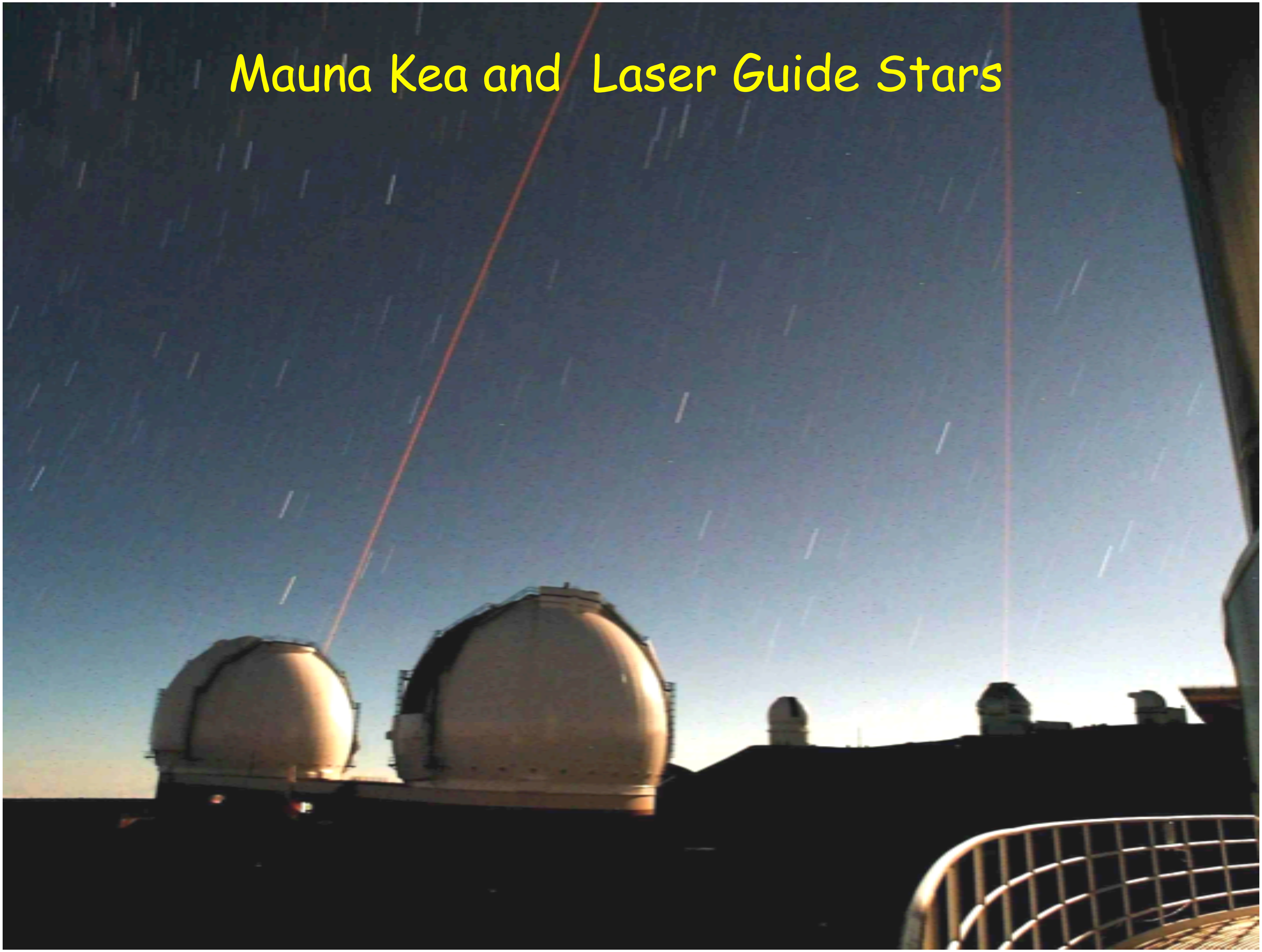
Lyα (z=2.84) Line Image (NB-V)



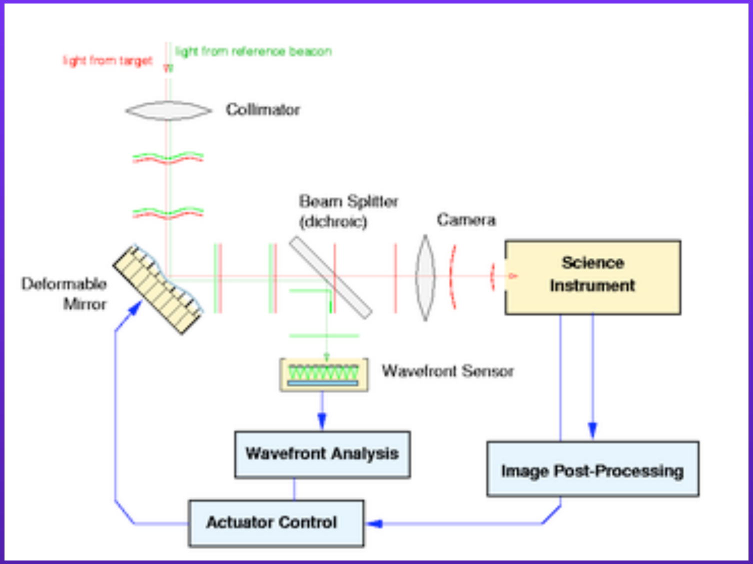
Food for Thought…

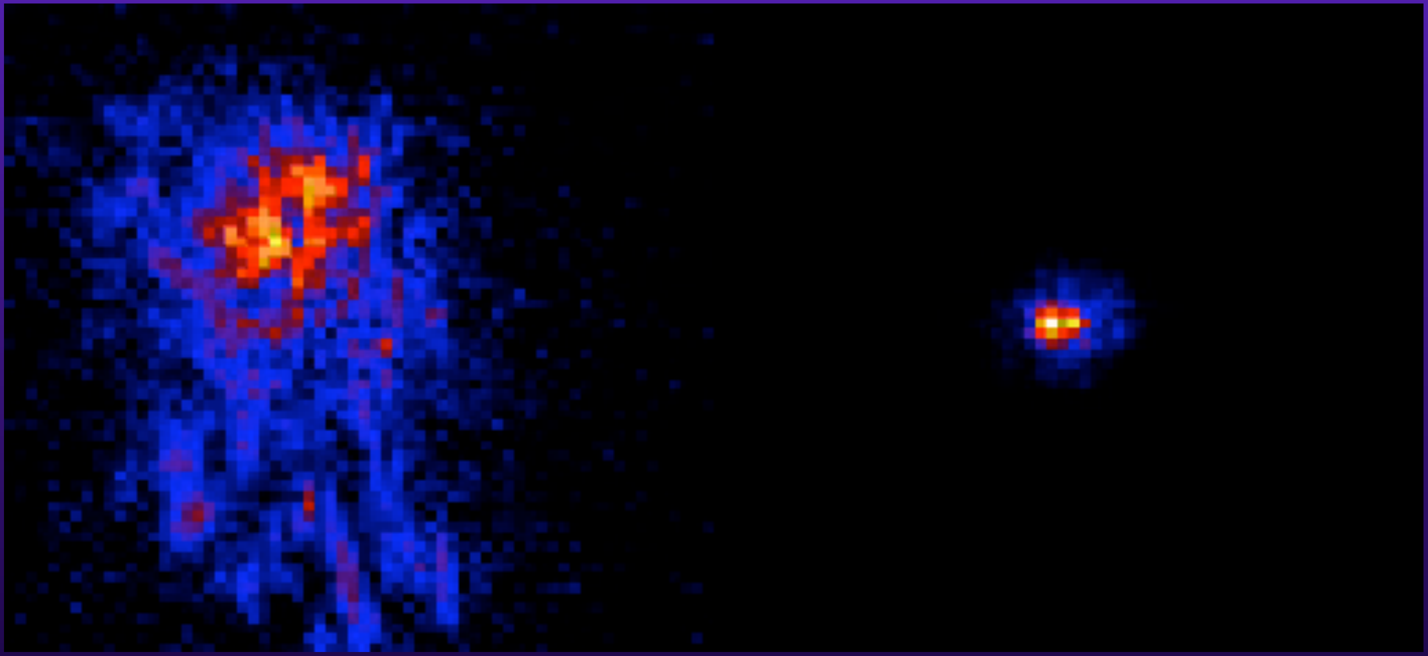
- The chemical elements making up you, and the chair you are sitting on, were produced inside stars that died ~10-12 billion years ago (the ultimate re-cycling program!)
- We can watch all the action in real time …. but in a distant part of the universe.
- Telescopes are basically time machines allowing dissection of "living specimens" of pre-historic denizens of the universe.
- We are sure to (continue to) be surprised as we poke around using new and different tools.

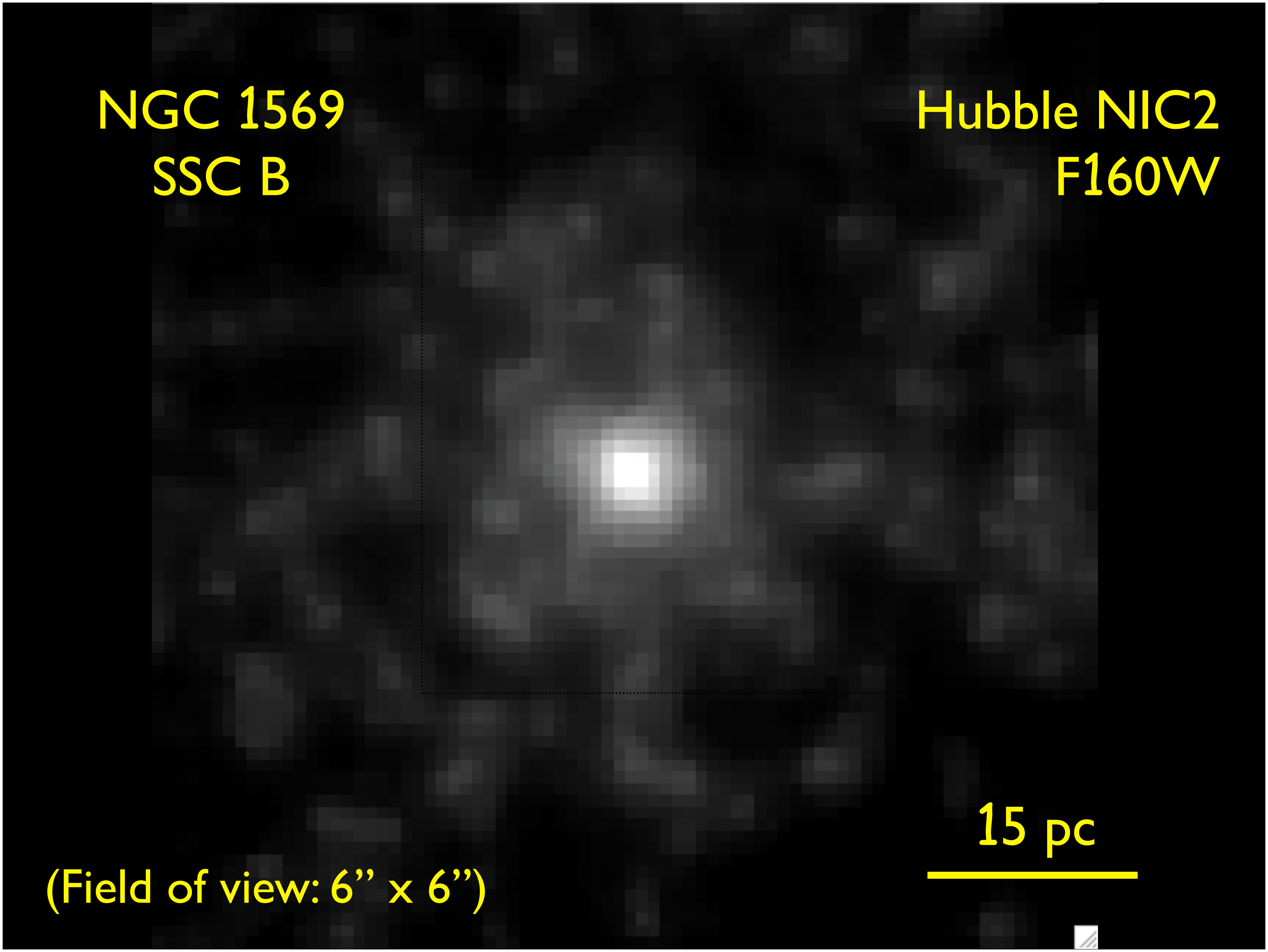
Mauna Kea and Laser Guide Stars

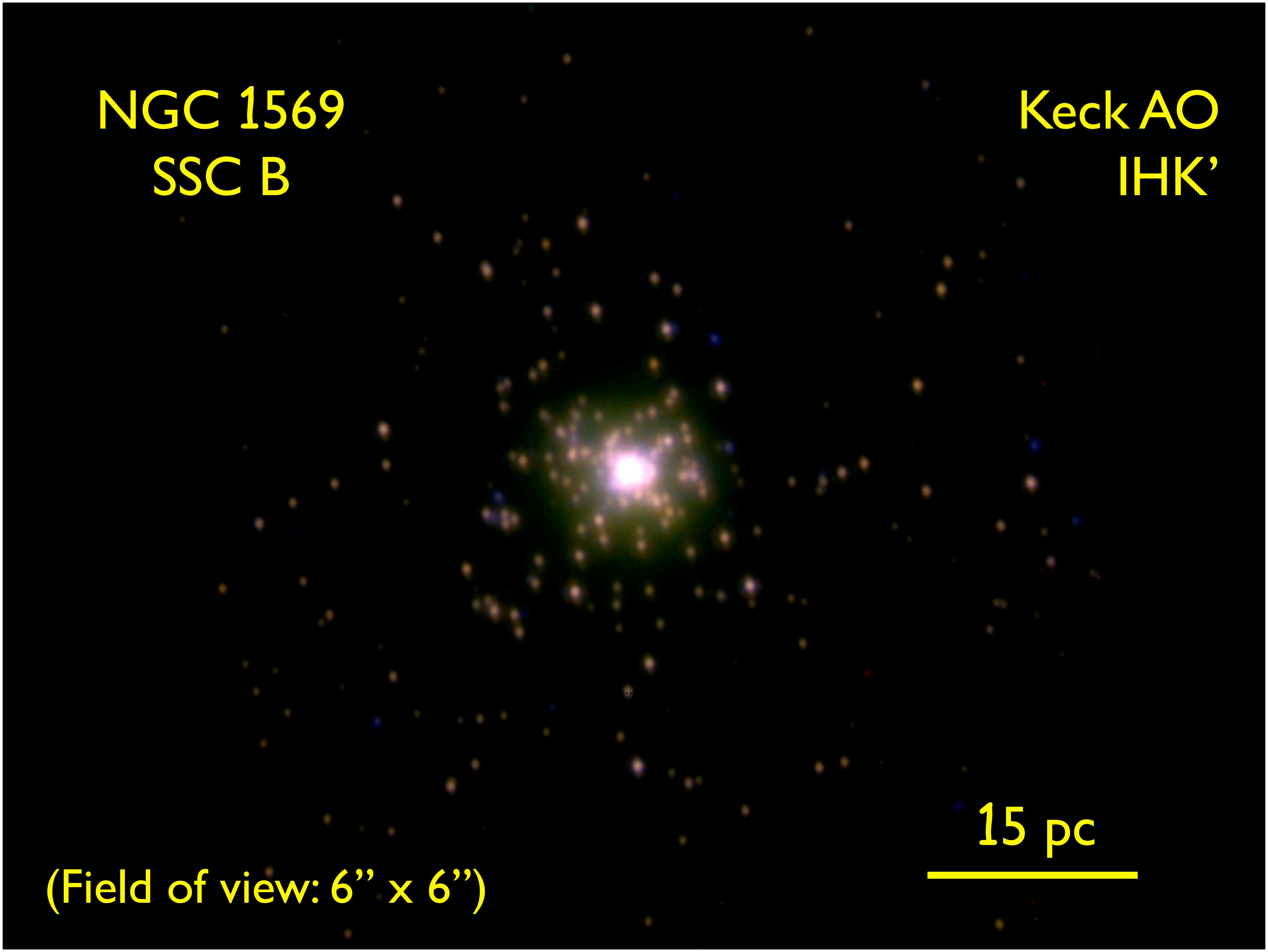


Adaptive Optics: How it Works

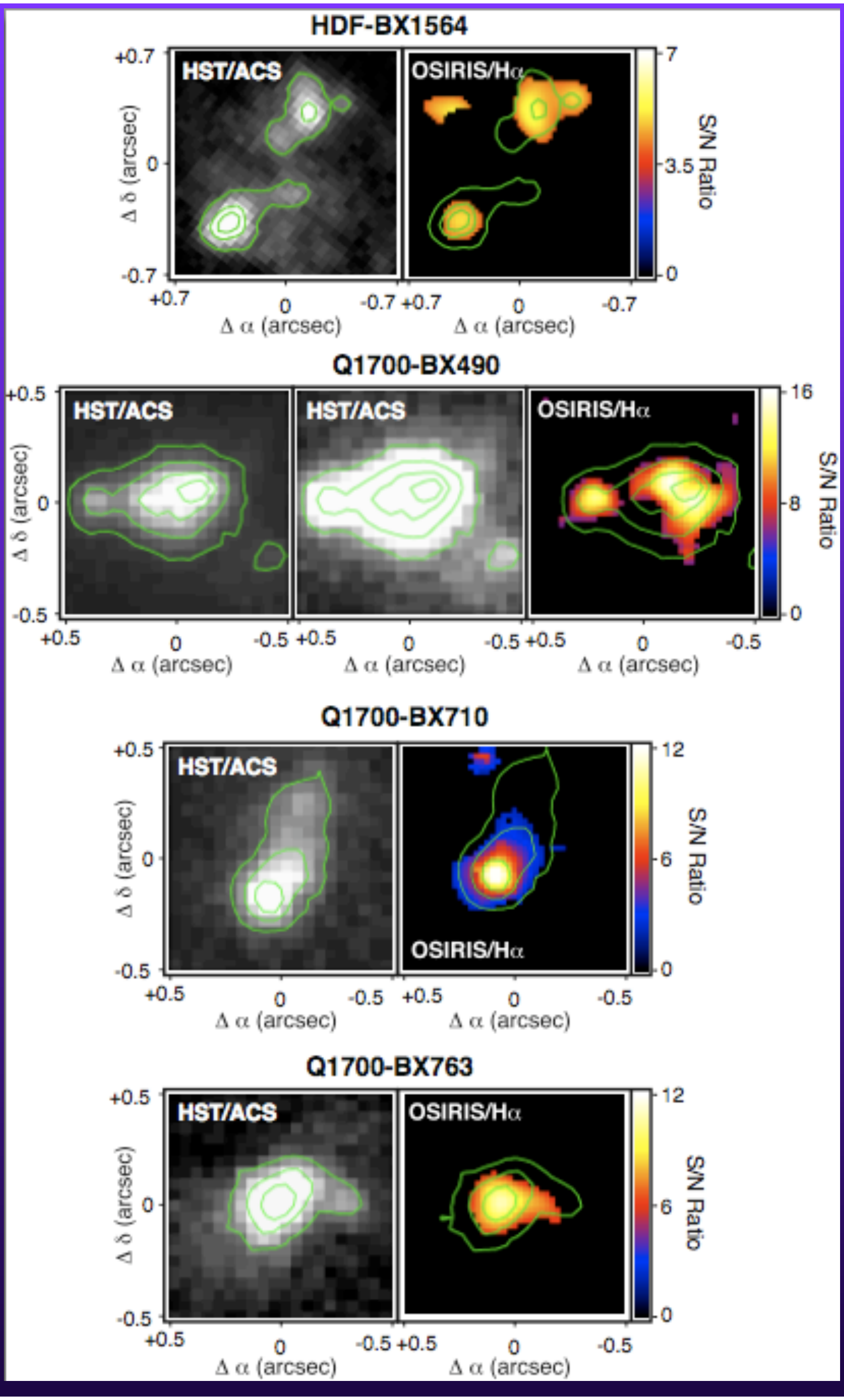




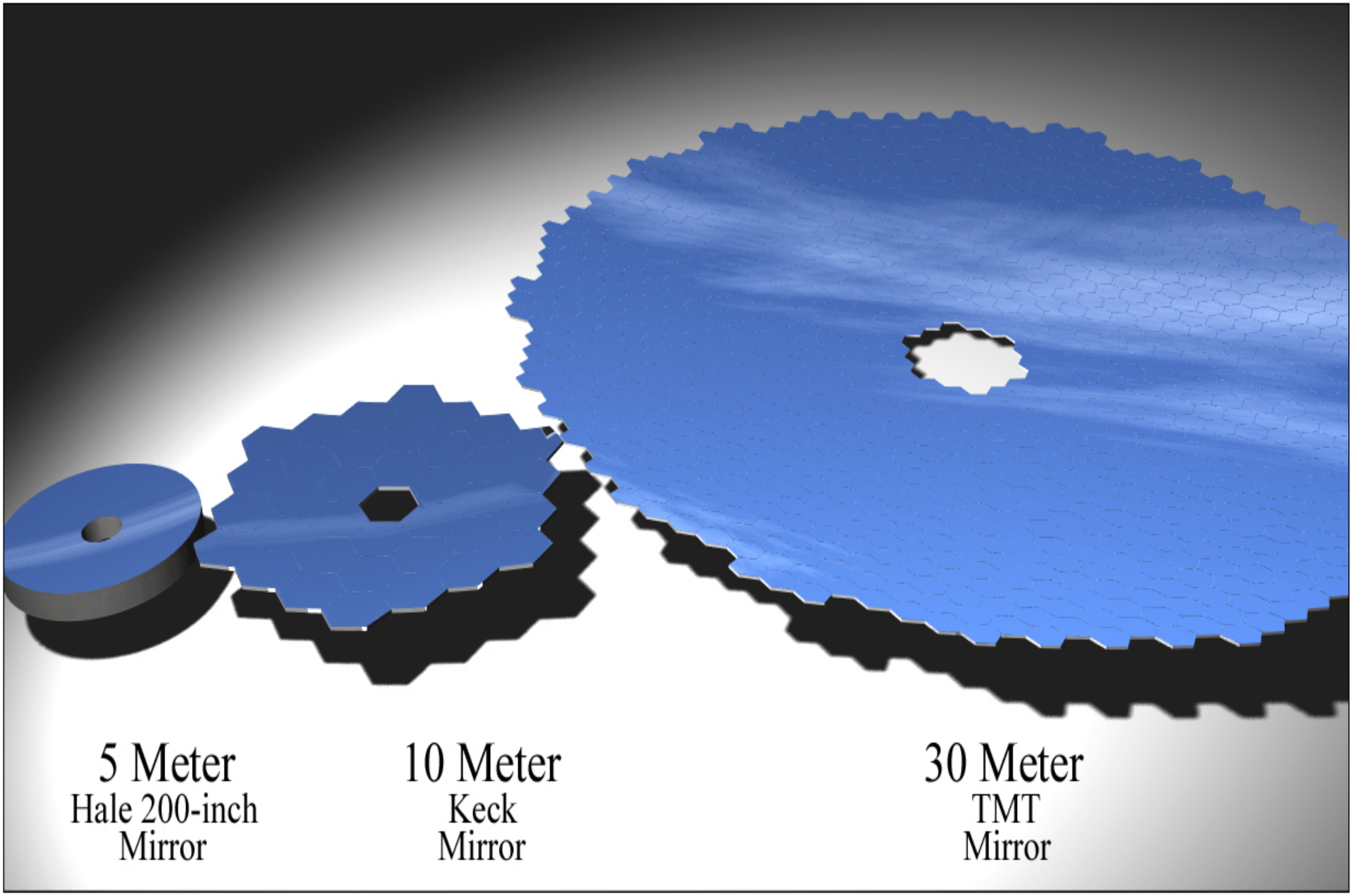

NGC 1569
SSC B
Hubble NIC2
F160W
15 pc
(Field of view: 6” x 6”)


NGC 1569
SSC B
Keck AO
IHK’
15 pc
(Field of view: 6” x 6”)

Maps of z~2.3 Galaxies vs. Hubble ACS

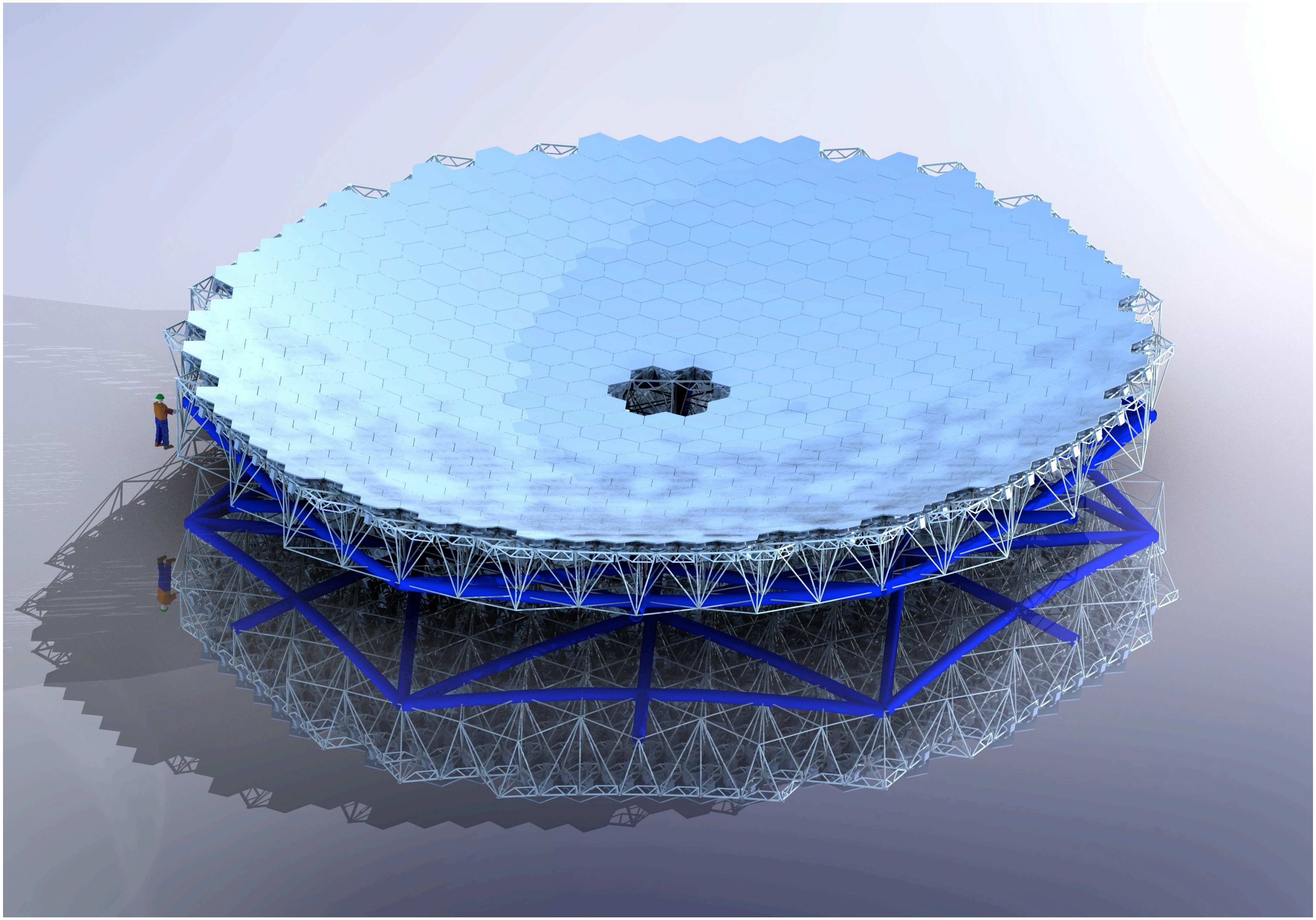


Keck II/OSIRIS+Laser Guide Star Adaptive Optics Resolution ~ 0.08" (~2 times better than Hubble)


5 Meter
Hale 200-inch
Mirror
10 Meter
Keck
Mirror
30 Meter
TMT
Mirror

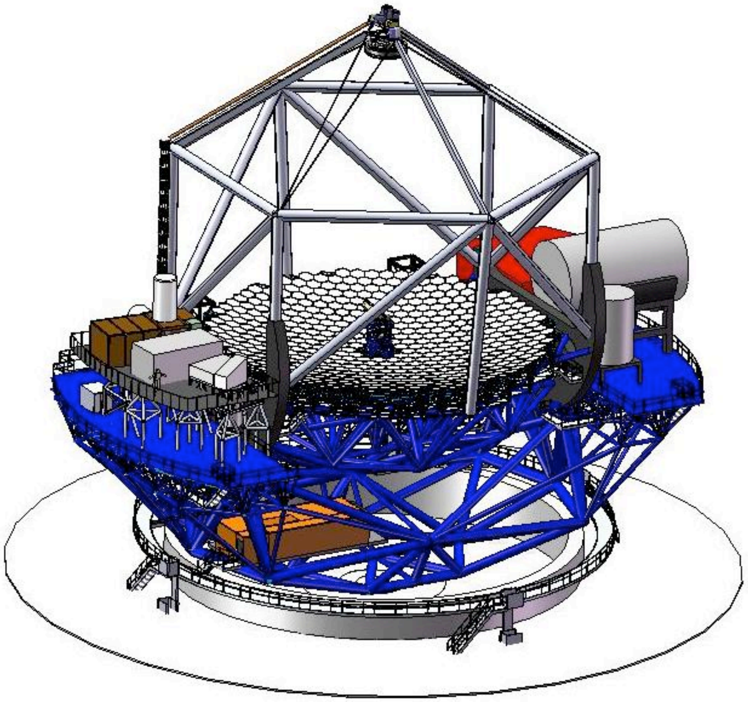
Primary Mirror: 492 × 1.4m segments

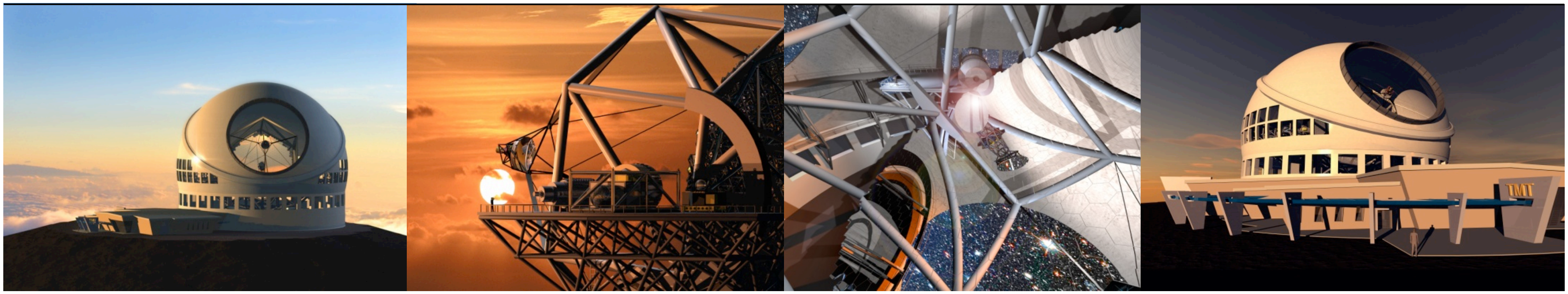
TMT



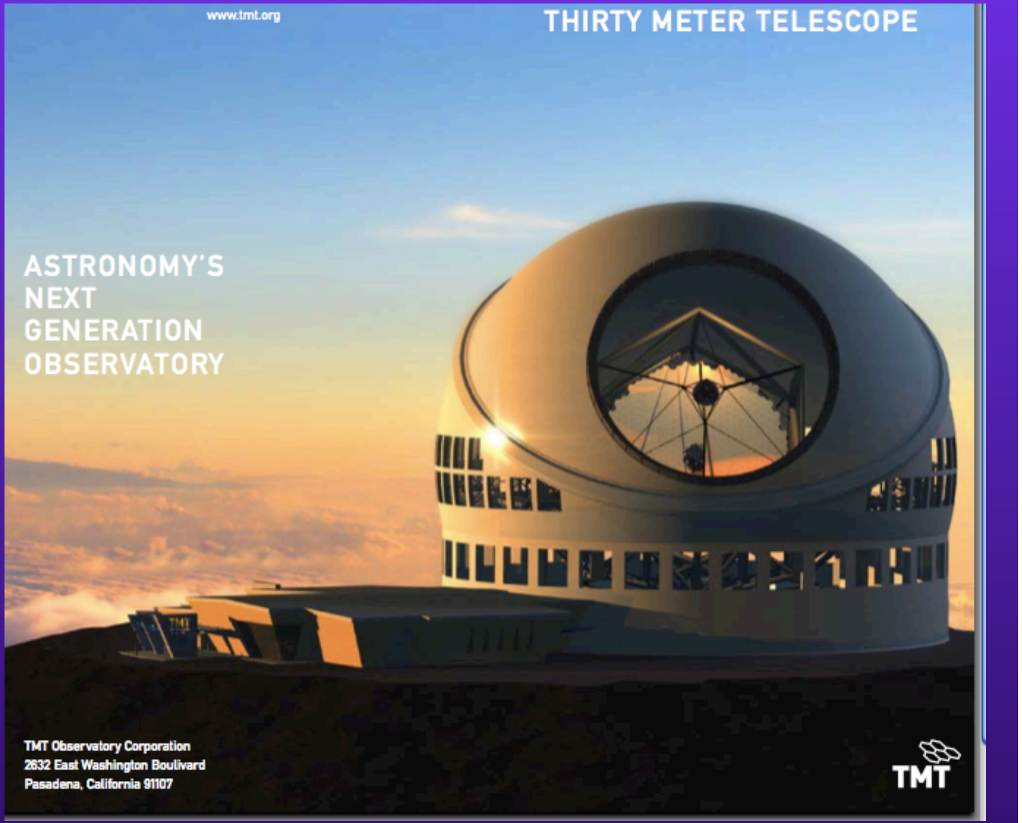
TMT: Fast Facts

- 30 meter (98-ft) diameter, filled aperture, 492-segment primary mirror
- Three-mirror telescope
- f/1 primary
- Field of view 20 arcminute
- Site: Mauna Kea, HI or Cerro Armazones, Chile
- Wavelength 0.31 – 28 μm
- Fully integrated adaptive optics
- Partners: Caltech, UC, Canada, Japan,+





Thirty Meter Telescope (TMT)
(www.tmt.org)



TMT Observatory Corporation
2632 East Washington Boulivard
Pasadena, California 91107

UC, Caltech, Canada,
Japan, +

First light: 2018

END of SLIDES SHOWN