CfAo Treasury Survey (CATS): Motivation & Vision

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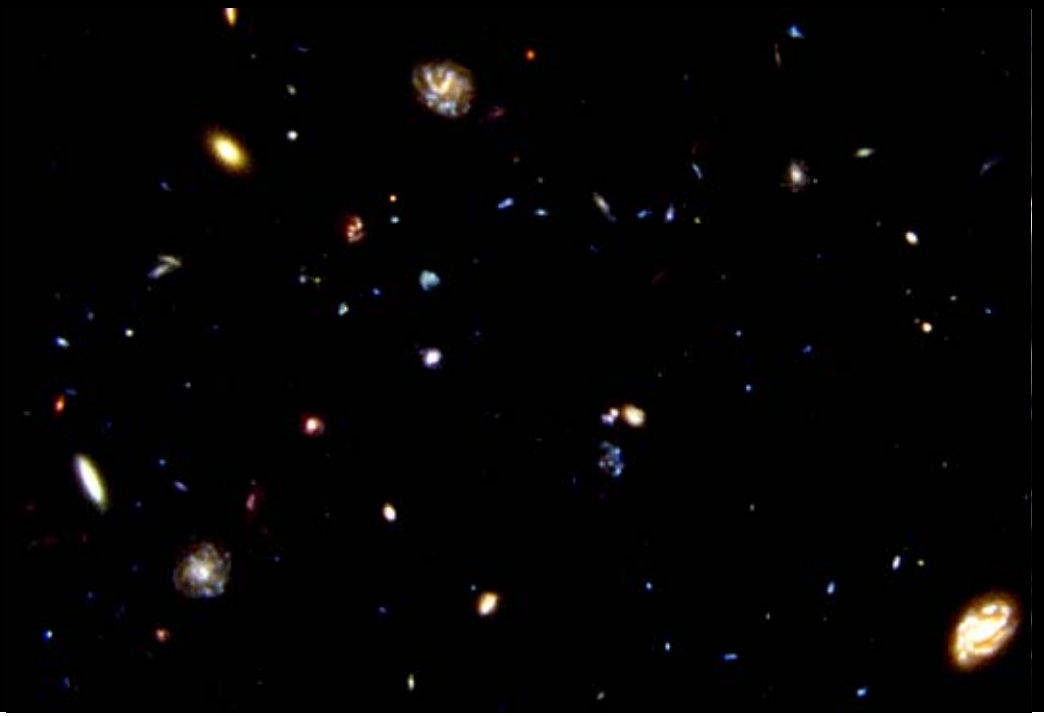


WHO & From WHERE?

- **P.I.** Jerry Nelson **(UCSC)**
- **co-PI:** David Koo (UCSC)
- **co-PI:** James Larkin (UCLA)
- **co-PI:** Tom Soifer (Caltech)
- Matthew Barczys (UCLA)
- S. M. Faber (UCSC)
- James Graham (UCB)
- Raja GuhathaKurta (UCSC)
- Claire Max (UCSC)
- Keith Matthews (Caltech)
- Jason Melbourne (UCSC)
- Eric Steinbring (UCSC)

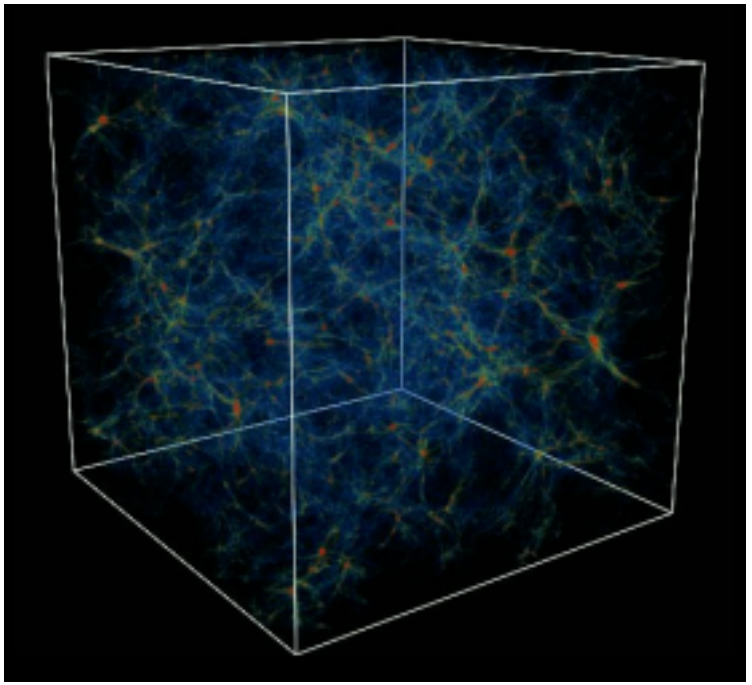
Cosmic Microwave Background at Redshift z ~ 1500

FACE of GOD !

Hubble Deep Field South at Redshifts z ~ 0 to 6

Galaxy Formation Models

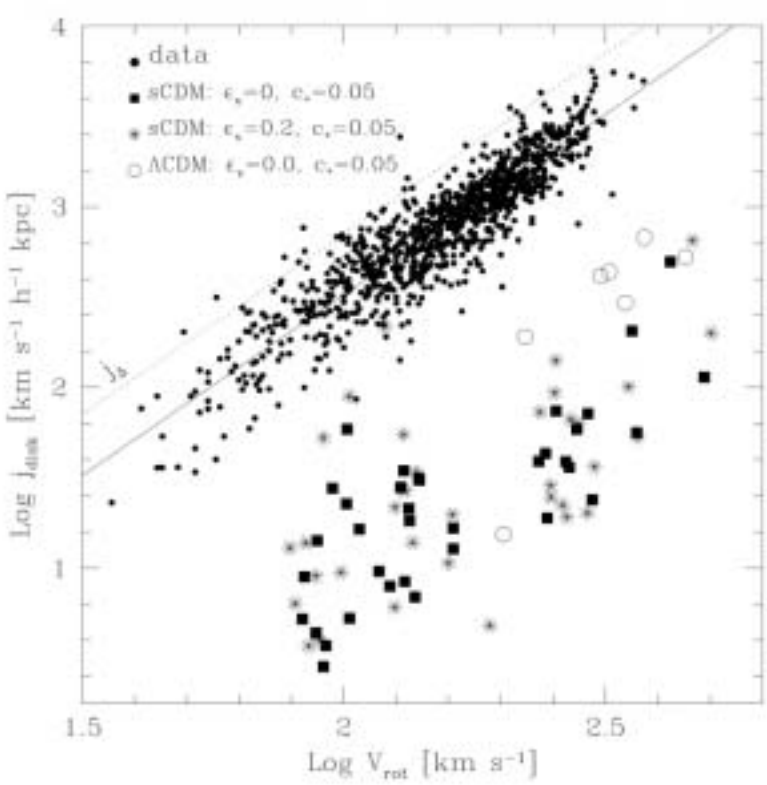
- Cold Dark Matter (CDM) is the dominant component of galaxies and is key to their formation & evolution.
- CDM models have been very successful at explaining large scale clustering.
- Dark matter also explains observed cosmic nucleosynthesis and baryon fractions.



Greg L. Bryan &
Michael L. Norman, 1998

Galaxy Formation Models

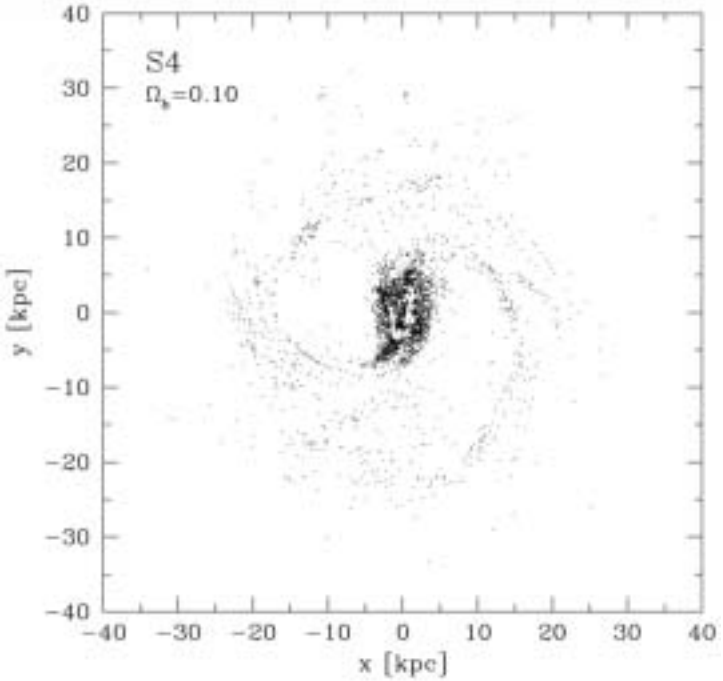
- But recent, more complex hydrodynamic models with Baryons have been miserable in creating large disk galaxies
- Model galaxies lose 10 times too much angular momentum!!
- Also over predicts number of dwarf galaxies by large factors.



Navarro & Steinmetz, 2000

Galaxy Formation Models

- New Models doing better by adding new physics or varying dark matter.
  - Dark Energy – Cosmological Constant (**L**CDM)
  - Early Star formation to heat gas and prevent premature collapse
  - Self-interacting cold dark matter.
  - Warm dark matter (WDM)
- Models make different predictions about the onset of star formation and AGN activity, formation of the bulge, merger fractions and dwarf galaxy population.



WDM simulation (largest galaxy produced) Sommer-Larsen & Dolgov, 2001

We can directly test these models by observing the evolution of disks, bulges, star formation rates, AGN, and mergers.

What is CATS ?

CfAO 6 Year Major Legacy Science Project

- Scientific Motivation: Formation & Evolution of Galaxies & AGN; Nature of Dark Matter & Energy
- Basic Data: NIR-AO Imaging and Spectroscopy in GOODS (+ other possible fields) at 10-20N/yr
- Targets: Faint Galaxies, AGN, & Distant SN
- Performance: best possible within AO technologies & instruments using Keck, Gemini, & TBD
- Deliverables: public database, analysis algorithms, simulations, & education/public outreach materials

What is GOODS?

Great Observatories Origins Deep Survey

- 2 Regions of Sky: HDF-N, CDS, each 160 sq'
- Wide wavelength coverage: optical & near-IR (HST & ground); deep-UV (GALEX); X-ray (Chandra & XMM); mid&far-IR (ISO, SIRTF); radio(VLA); submm (SCUBA, LMT)
- Performance: Deepest & Highest Spatial Resolution:
- Science: Broad range -- Galaxy formation and evolution; AGN - nature and evolution; High z Supernovae; gravitational lensing; IGM properties
- Members: International with over 100 scientists

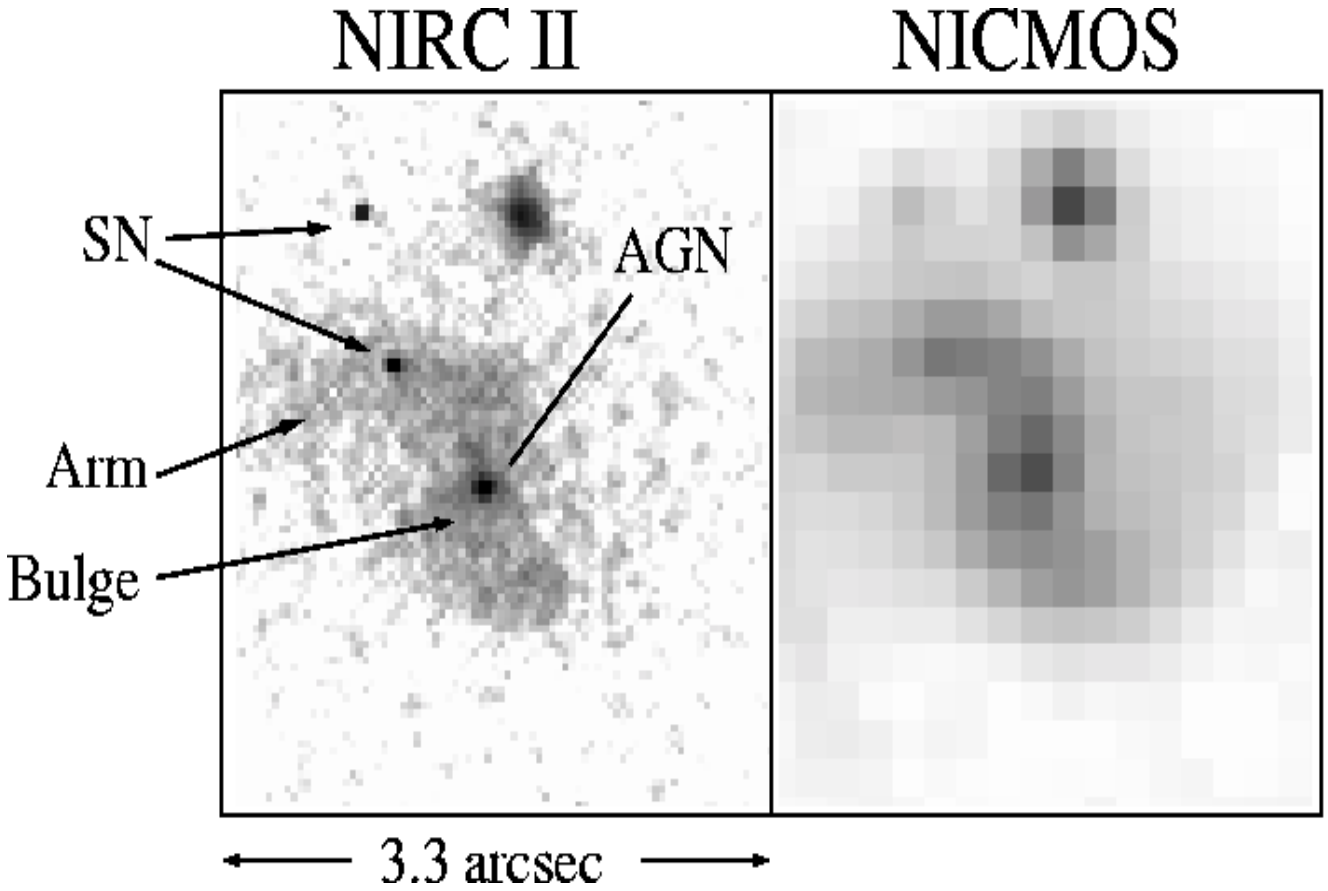
Why GOODS for CATS?

- High Leverage for data and science return
- High Visibility by broad astronomical community.
- Long-Term benchmark for AO advances with
- Multi-levels of Independent checks of performance, efficiency, errors, etc.
- GOODS missing 0.05 arcsec NIR images - CATS will provide UNIQUE & VALUABLE data

Why NIR-AO?

- Near-IR: gives rest-frame optical at high-redshift, less sensitivity to dust extinction, better measures of old stars
- Imaging: 0.05" resolution needed to discern the key subcomponents of galaxies (bars, spiral arms, bulges); measure accurate brightness of nuclear emission from AGN, starbursts, or supernova atop its host galaxy
- Repeat Imaging: variability data to find supernovae used for measuring dark energy and dusty AGN to study the evolution of massive black holes.
- Spectroscopy: detailed internal kinematics, dust extinction, star formation rates, metallicities, and ages of stars and gas to study the formation and evolution of distant galaxies and their relationship to dark matter.

Keck AO vs. HST NICMOS



Simulated H ~ 20.2 distant spiral galaxy using 2H Keck AO and 0.015’’/px and HST NICMOS with 0.2’’/px. The SN and AGN are each H ~ 25, the expected peak brightness of a z~1.7 SN. This simulation was kindly made by R. Bouwens,

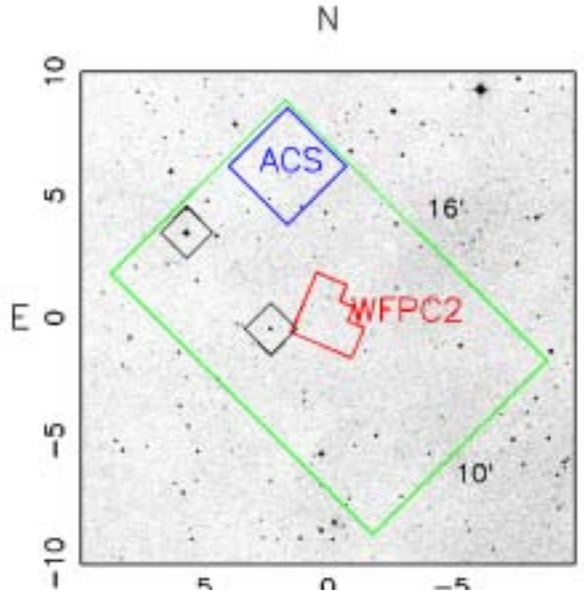
Why the C in CATS?

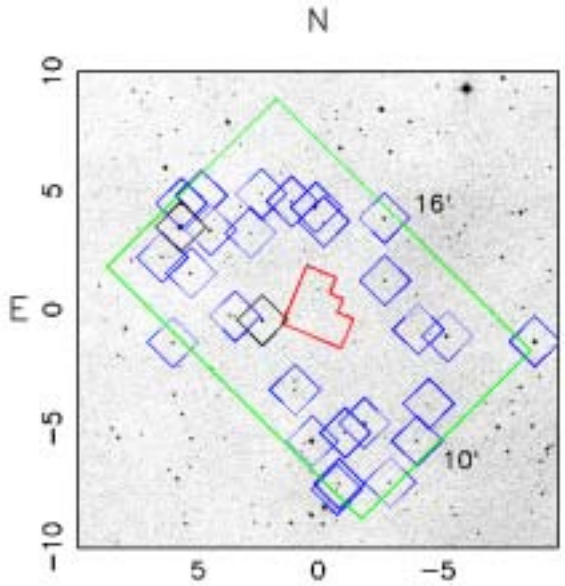
- CENTER MODE - unifies disparate parts
- COMMUNITY LINK - visibility for AO
- COOPERATION with other groups/obs
- COSMOLOGY SCIENCE DRIVERS
- CHECK of AO Technologies/Performance
- C-ELT PATH for MCAO - science & tech.

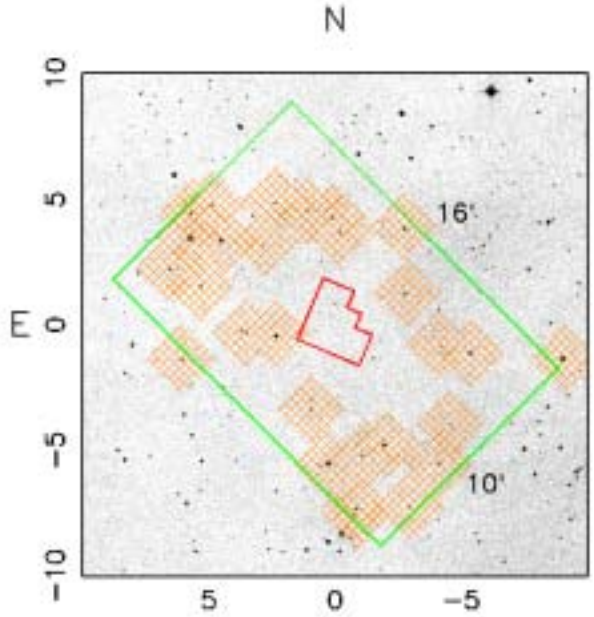
CATS ISSUES for Discussion

- Long-term observing plan, schedule, costs, and strategies (Larkin)
- Which science areas - subset of Galaxies? SN? AGN?
- What simulations? Science, instrument, project planning, error analysis, etc.
- What collaborations? GEMINI, VLT, etc.
- What archive and database system and release policy?
- Education and public outreach products?

GOODS-N Coverage by AO







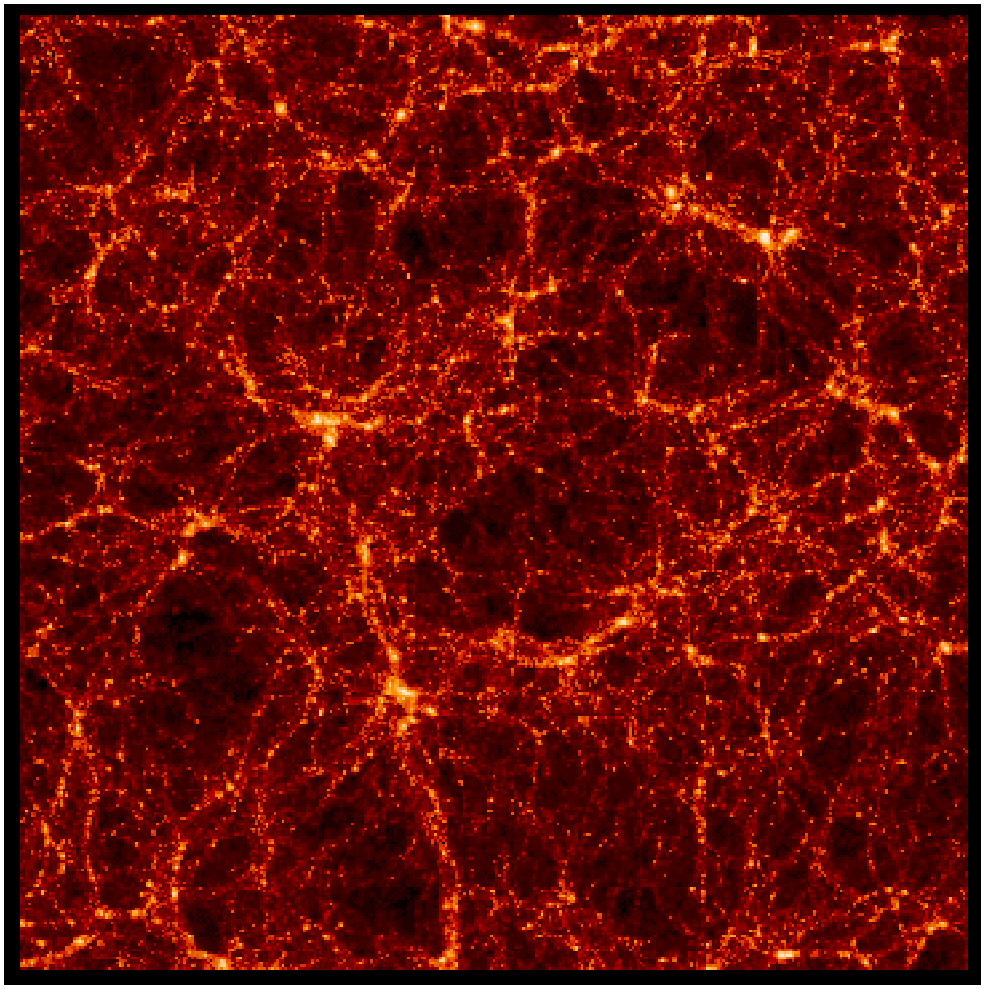
- GOODS (green) and AO-accessible regions. The upper-left panel shows ~3% coverage around two NGS (V<13); upper-right shows 30% coverage using LGS around tip-tilt stars V < 18; lower-left shows coverage of ~50% anticipated by using MCAO on GEMINI.

Cosmological Conundrums

1) **What is the nature of Dark Matter?**

Based on observations on the scale of galaxies (few kpc) to clusters of galaxies (few Mpc), astronomers have discovered that about 90% of the matter in the Universe appears *not* to be made of baryons. The nature of this non-baryonic Dark Matter remains one of the major cosmological mysteries to be solved in the 21st C. Astrophysical data using large samples of distant galaxies can be used to probe the evolution in their dynamical (dark and baryonic) masses and small to large scale structures (sensitive to whether the dark matter is hot, warm, or cold or some combination). Distant galaxies are thus expected to play an important role in deciphering this puzzle.

Simulation of Universe at Redshift z =1



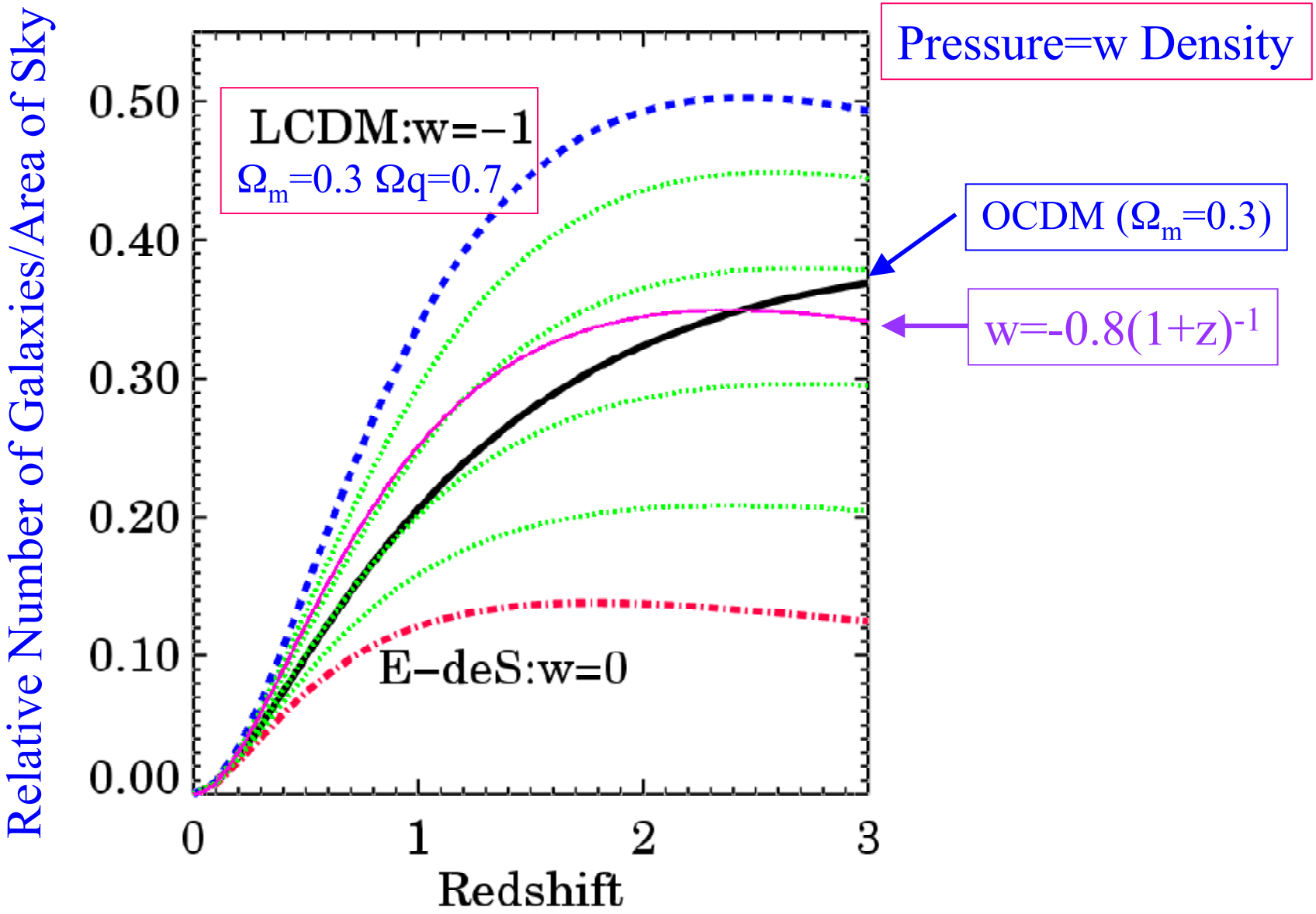
z=1 ΛCDM simulation from VIRGO Consortium (White 1997)

Cosmological Conundrums

2) **What is the nature of "Dark Energy"?**

The combination of finding a flat Universe from microwave background measurements and an accelerating Universe from the dimming of distant supernovae, suggests that the geometry of the Universe is dominated by Einstein's "greatest blunder" -- the cosmological constant. This "constant" may be variable and is also known as "dark energy" , quintessence, or vacuum energy. Physicists are off by 10^{120} in estimates of the expected value of this "constant". Distant galaxies and associated supernovae provide important clues to this outstanding astrophysical, cosmological puzzle by tracking the evolution of cosmological curvature ("equation of state") via volume or luminosity distance measurements.

Counts of Galaxies vs "Equation of State"



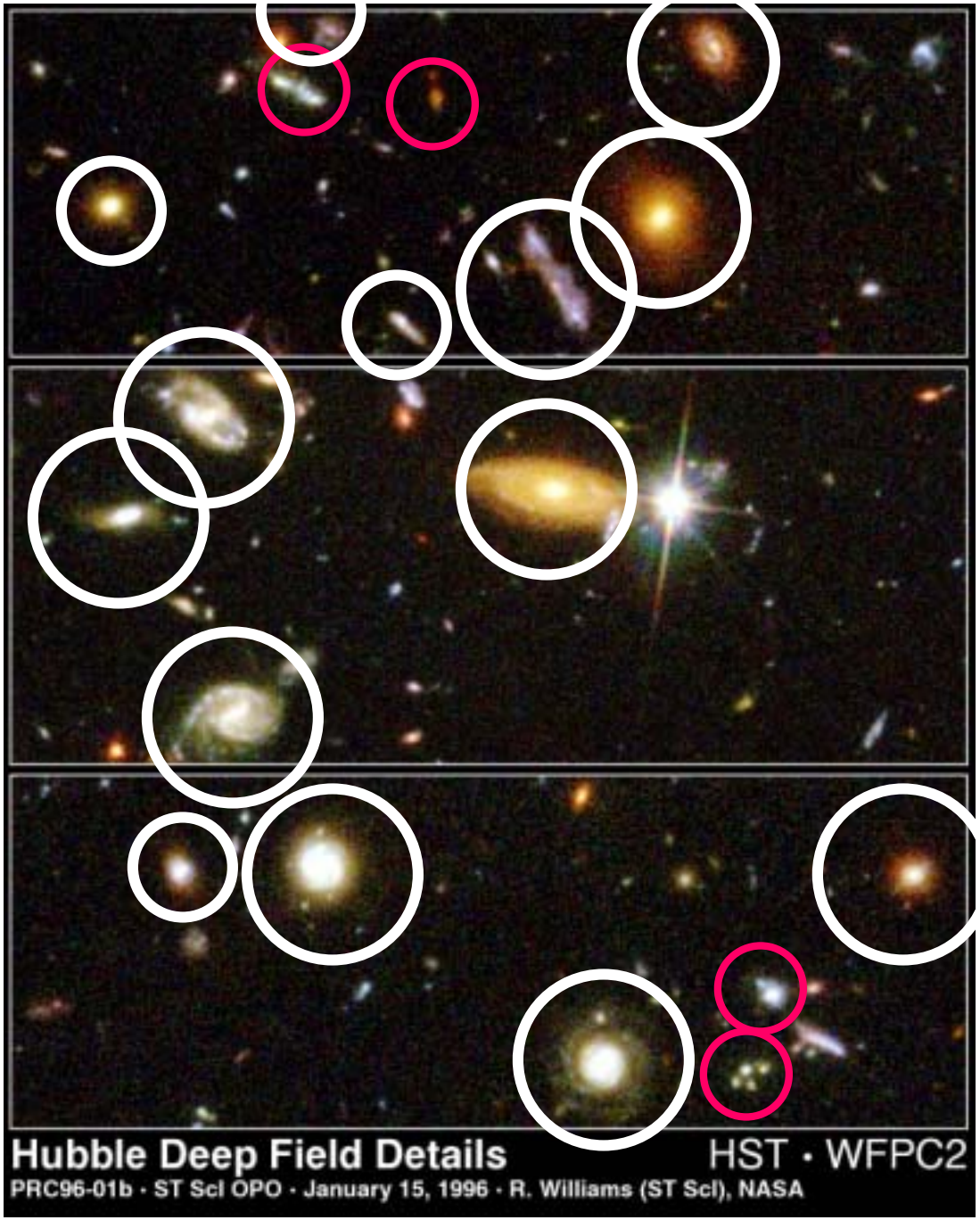
Cosmological Conundrums

3) **When and how did galaxies form and assemble?**

The Hubble Deep Fields, the deepest optical images of the of the Universe, reveal a sea of tiny blobs at redshifts beyond $z \sim 2$, and yet quite ordinary spirals and ellipticals by $z \sim 1$. Theory strongly suggests that galaxies form from hierarchical buildup of smaller fragments to larger bodies. How did galaxies make the transition is one of the major areas of research worldwide in observational cosmology. Many key mysteries remain:

- How did galaxies acquire their diversity of morphologies?
- How old are the bulges versus their disks?
- What is the relationship between massive black holes (active galactic nuclei) and galaxy formation?
- What has been the star formation history of different galaxy types?
- What role does environment (pairs, groups, clusters) play?

High z > 2



Low z ≤ 1

M31 Andromeda Galaxy