Galaxies: Structure, formation and evolution

Lecture 21

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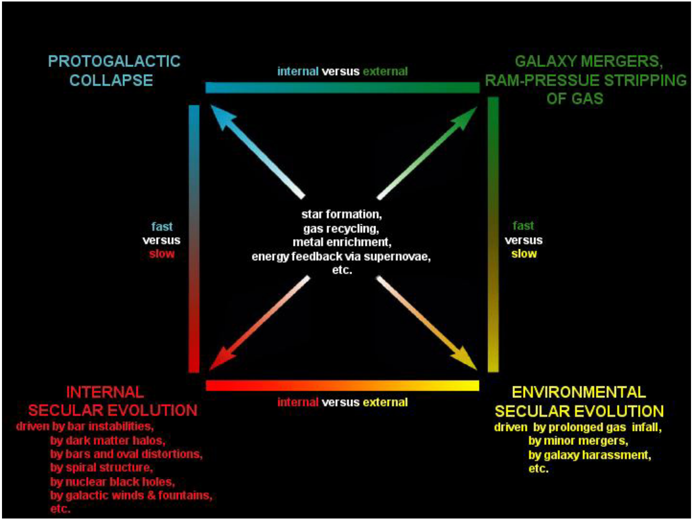
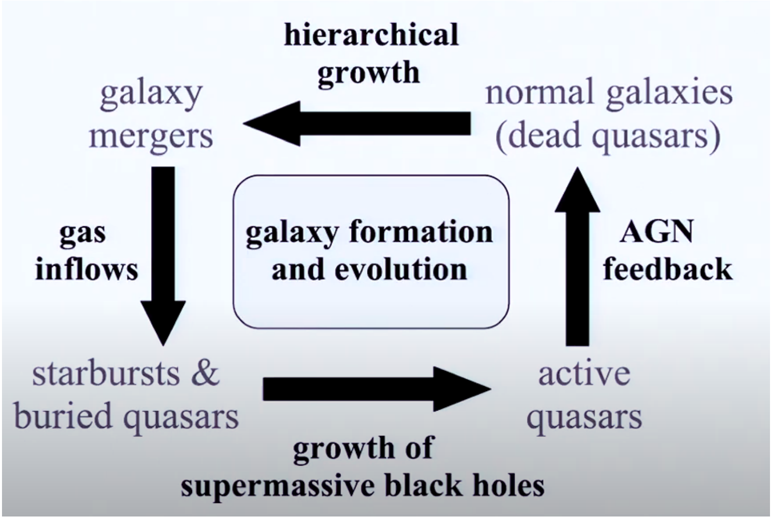
Galaxy formation and evolution in one diagram



see review by Kormendy & Kennicutt (2004)

Feedback and galaxy evolution



Credit: Phil Hopkins

Galaxy formation - proto galaxy definition

- Galaxy in the first X % or Y yrs of its life (X=?, Y=?)
- Galaxy which has formed X % of its stars (X=?)
- Galaxy which has assembled X% of its final mass (X=?)
- Initial density fluctuation which has not formed any stars yet
- Galaxy at a very high redshift z > Z (Z=?)
- Generally we think of the progenitors of massive galaxies today, roughly in the first Gigayear of their life, i.e., at $z \gtrsim 5$
- We certainly expect vigorous star formation to be occuring, and therefore luminous objects

Dissipation in galaxy formation

Galaxies collapse and cool. The binding energy released is:

$$|E_{bind,gal}| \simeq 1.2 \times 10^{59}\mathrm{erg} \times (M_{cool}/10^{11} M_{\odot})(V_{3D}/250\mathrm{kms}^{-1})^2$$

where M_{cool} is the total mass that can cool radiatively.

Binding energy released by collapsing protostars

$$|E_{bind,\star}| \simeq 4 \times 10^{58} erg \times (M_{\Sigma\star}/10^{10} M_{\odot})(\langle M \rangle / M_{\odot})(\langle R \rangle / R_{\odot})^{-1}$$

$M_{\Sigma\star}$ is the total mass converted to stars, $\langle M \rangle$ is the average star mass and $\langle R \rangle$ is the average star radius.

Energy release by nuclear fusion

$$E_{nuc} \simeq \epsilon M_{\Sigma\star} c^2 \Delta X \simeq 10^{60} \mathrm{erg} (\epsilon/0.001)(M_{\Sigma\star}/M_\odot)(\Delta X/0.05)$$

Energy release by early AGN

Using an average bolometric luminosity $\langle L_{bol} \rangle$ and the average duration of the active episode Δt

$$E_{AGN} \sim \langle L_{bol} \rangle \Delta t \simeq 1.2 \times 10^{60} \mathrm{erg} (L_{bol}/10^{10} L_{\odot})(\Delta t/10^{8} \mathrm{yr})$$

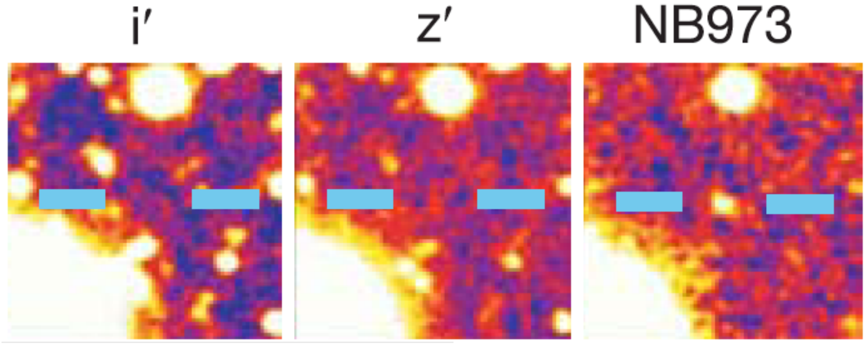
Timescale for energy release in a proto elliptical

We expect a release of $\Delta E \sim 10^{60}$ ergs from a typical protoelliptical but over what time scale?

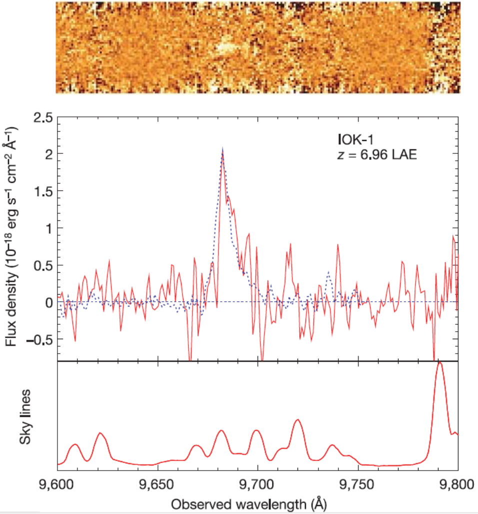
- The starburst time scale of $\sim 10^7 - 10^8$ yrs
- The free-fall time scale of $\sim 10^8$ yrs
- The merging time scale of $\sim 10^9$ yrs

This gives $L_{PG} \sim 10^{11} - 10^{12} L_\odot$. Given the luminosity distances to $z \sim 6 - 8$, the expected apparent magnitudes are in the range ~ 26 to 30 mag. A few % of the total energy is in recombination lines, e.g., Lyα. Is there dust obscuration? No: use optical/near-IR, Yes: use submm-FIR surveys

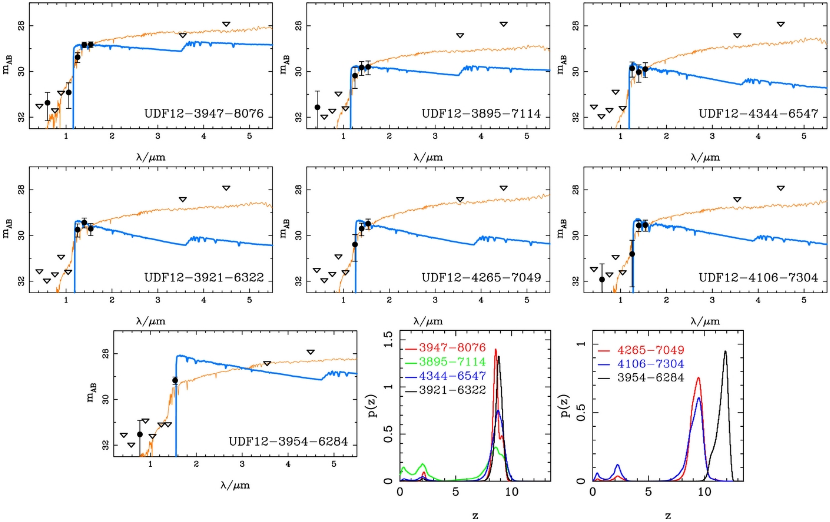
Finding these PG



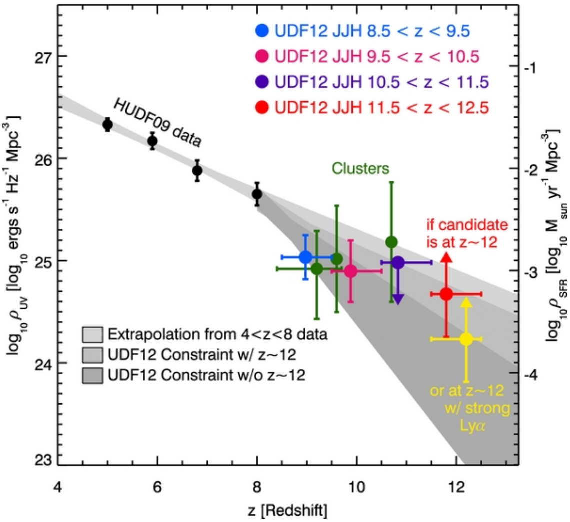
Spectroscopy confirms it



Highest redshift candidate galaxies via photometric redshifts



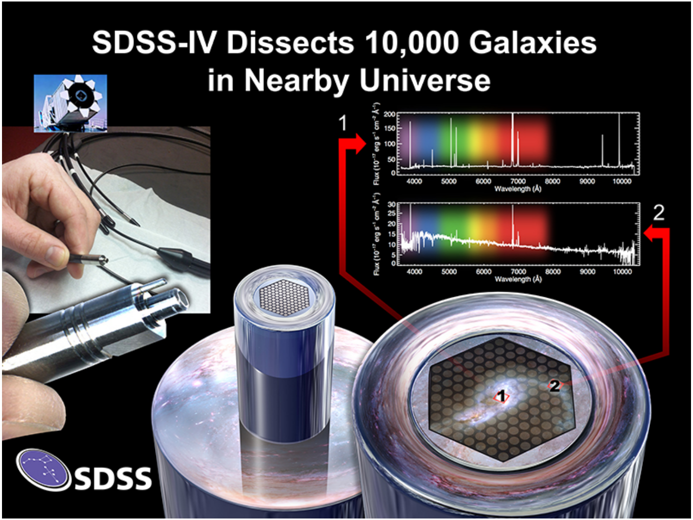
Madau diagram at high redshift



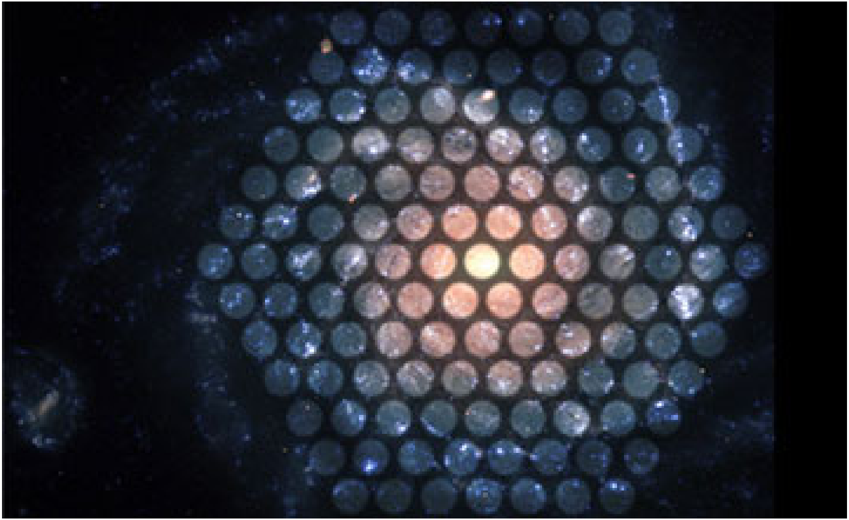
My course on galaxies has covered

- Background material and Overview 1 A brief History of extragalactic research 2 **Morphological Classification** 3 **Surveys & Quantitative morphology** 4 Galaxy Luminosity Functions
- Normal galaxies 5 Spiral and Irregular Galaxies 6 Stellar Kinematics I : Disks 7 Elliptical and Lenticular Galaxies 8 **Stellar Kinematics II : 3-D Systems** 9 Gas & Dust in Galaxies 10 **Population Synthesis**
- Interactions & activity
  11 **Star Formation & Starburst Galaxies** 12 Galaxy Interactions & Mergers 13 Galaxy Groups & Clusters 14 Galaxy Nuclei & Nuclear Black Holes 15 Active Galaxies & Quasars
- Formation and evolution 16 The Cosmological Framework 17 Growth of Structure 18 Galaxy Formation, **high** z **galaxies& Evolution** 19 Reionization & the IGM 20 Dark Matter & Gravitational Lenses

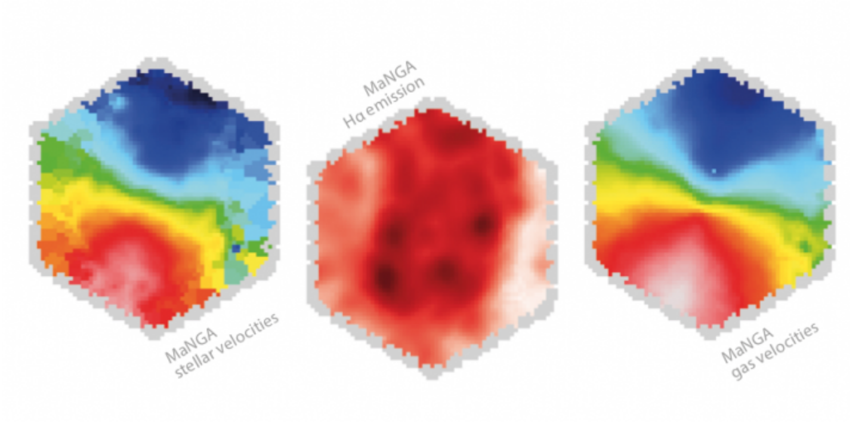
MaNGA survey



Tiling a galaxy with fibres



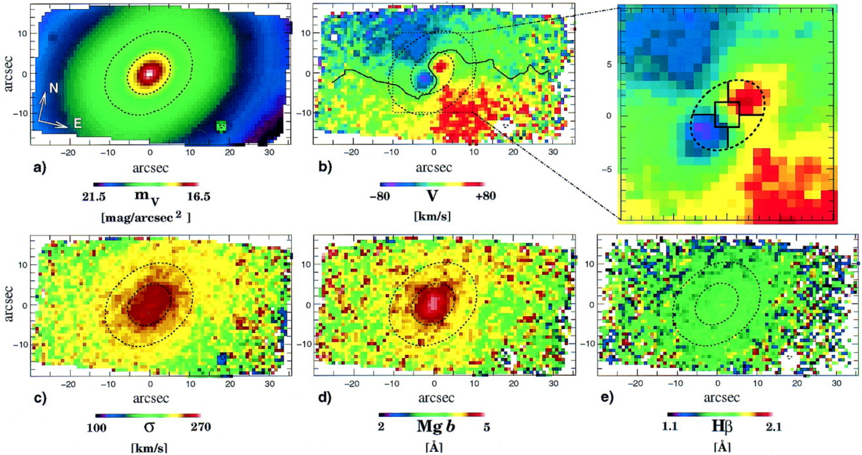
MaNGA survey - kinematics and chemical evolution



MaNGA in relation to other surveys

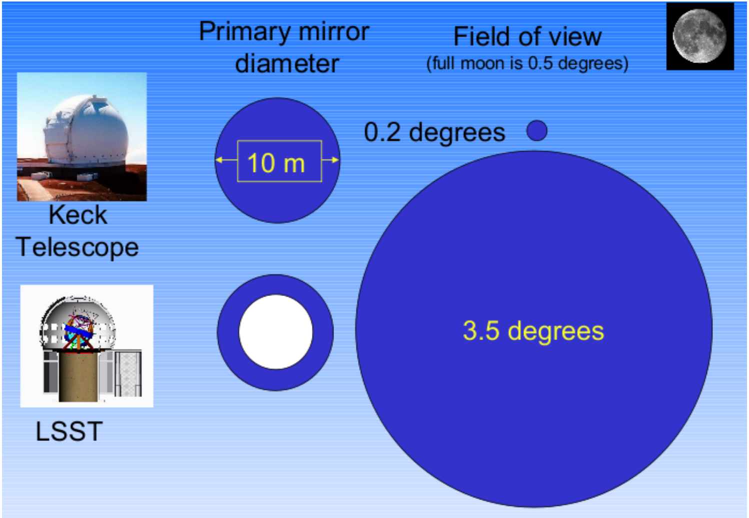
SAURON (lenslets), SAMI, CALIFA (fibers), MUSE (mini-slits)
There are now IFU (3D) spectrographs on most large optical telescopes of the world.
With SDSS V, the local volume mapper program will carry out IFU spectroscopy of the Milky way and nearby galaxies.
For multi-fiber spectroscopy, the DESI survey with its robotically positioned fibres will obtain spectra for millions of galaxies.

SAURON - now decommisioned

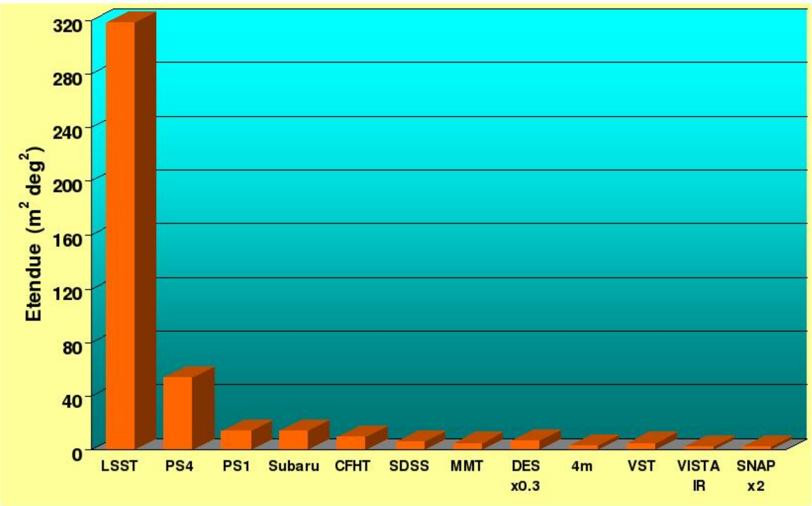


Rubin/LSST Observatory- Cerro Pachon

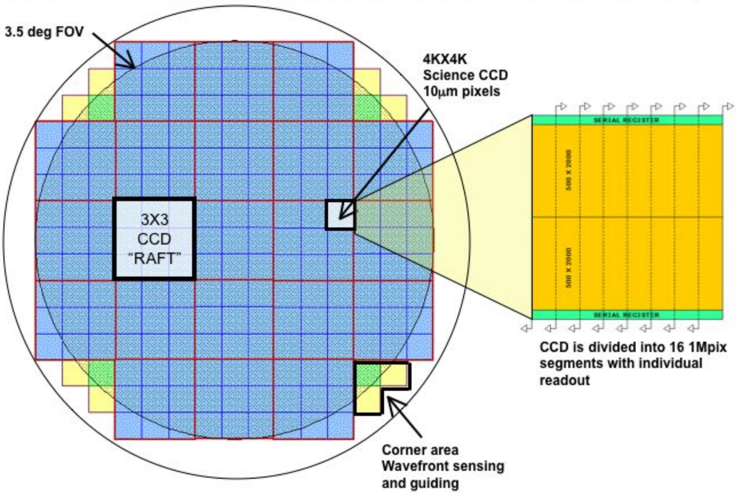
Etendue of Rubin/LSST compared to Keck



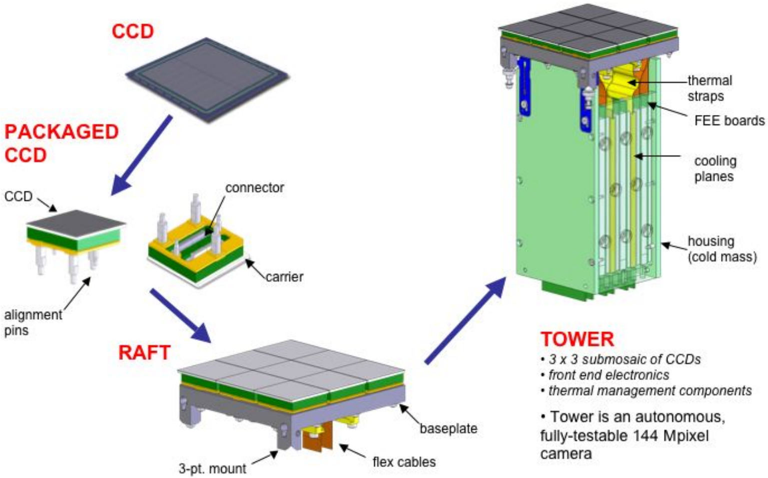
Etendue of Rubin/LSST compared to other telescopes



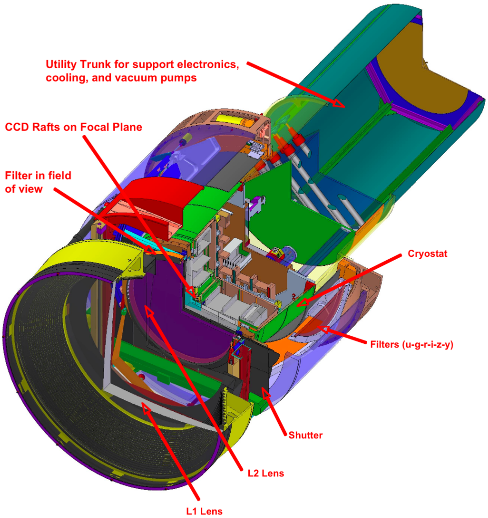
The LSST camera



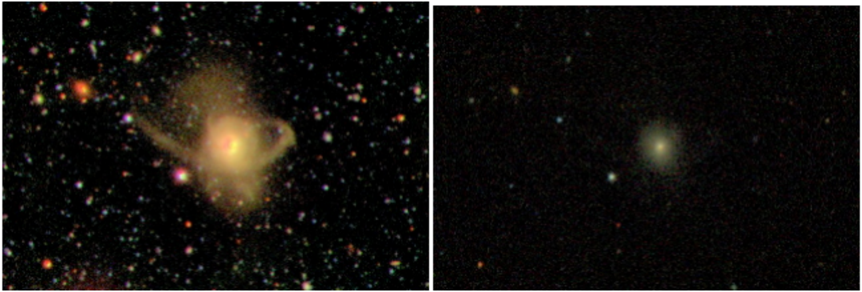
A LSST raft


CCD
PACKAGED CCD
CCD
connector
carrier
alignment pins
RAFT
baseplate
3-pt. mount
flex cables
thermal straps
FEE boards
cooling planes
housing (cold mass)
TOWER
• 3 x 3 submosaic of CCDs
• front end electronics
• thermal management components
• Tower is an autonomous, fully-testable 144 Mpixel camera

The LSST camera

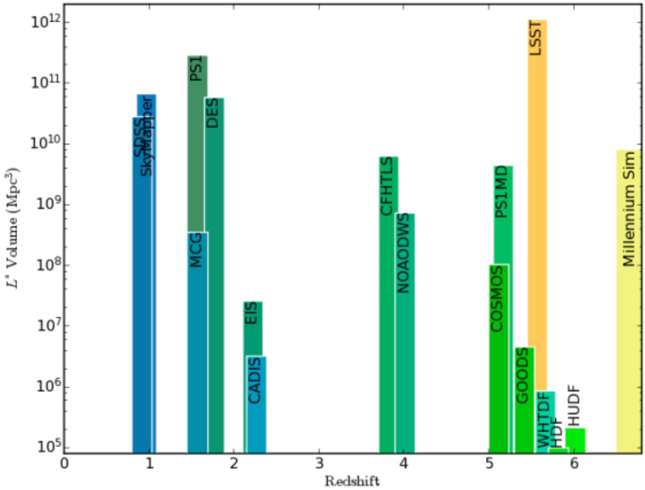


LSST versus SDSS depth

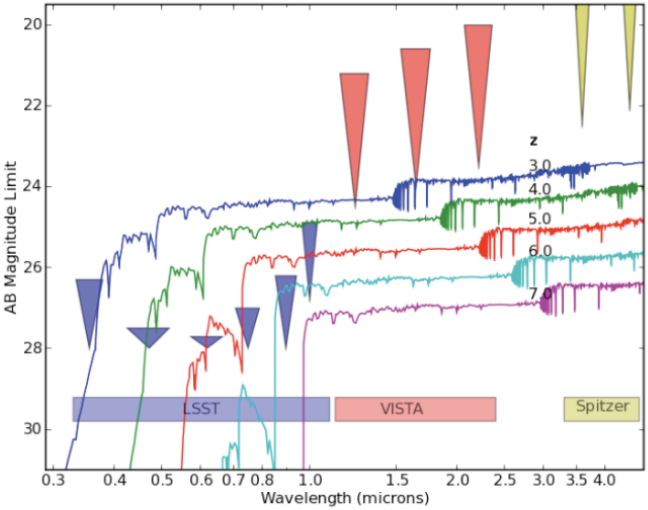


Many new dwarf galaxies will be detected

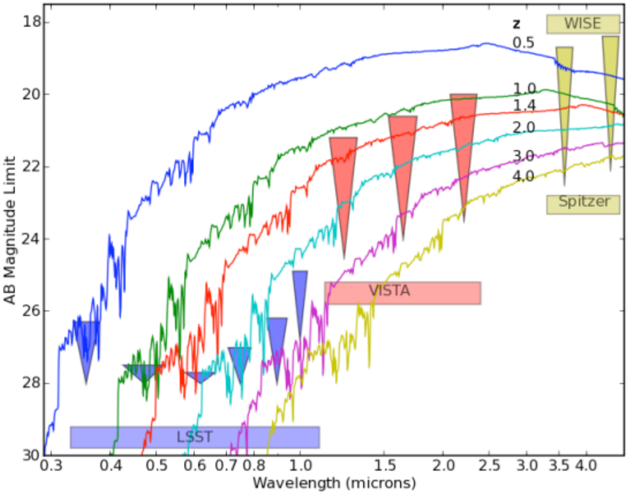
L_* volume sampled by different surveys



Distant Lyman break galaxies



Distant Red Sequence galaxies



Expected LSST areas of contribution

- Demographics of high redshift populations
- Demographics of LSB and dwarf galaxies
- Mergers, interactions and the environment
- Quantifying the biases and uncertainties
- Clusters and cluster galaxy evolution, intracluster light (intracluster novae)
- Observational confirmation of HOD
- many research projects could be done in citizen science mode.

Several Indian astronomers involved

IND-IUC	India	**Bhalerao, Varun**	IIT Bombay	PI
IND-IUC	India	**Biswas, Bhaskar**	IUCAA	JA
IND-IUC	India	**Bose, Sukanta**	IUCAA	PI
IND-IUC	India	**Chakraborty, Manoneeta**	IIT Indore	PI
IND-IUC	India	**Chaurasiya, Navin**	IUCAA	JA
IND-IUC	India	**Stalin, Chelliah Subramonian**	IIA	PI
IND-IUC	India	**Choudhary, Sunil**	IUCAA	JA
IND-IUC	India	**Dasgupta, Basudeb**	TIFR	PI
IND-IUC	India	**Datta, Abhirup**	IIT Indore	PI
IND-IUC	India	**Ganeshaiah Veena, Punyakoti**	TIFR	JA
IND-IUC	India	**Khatri, Rishi**	TIFR	PI
IND-IUC	India	**Kulkarni, Girish**	TIFR	PI
IND-IUC	India	**Kumar, Harsh**	IIT Bombay	JA
IND-IUC	India	**Majumdar, Subhabrata**	TIFR	PI
IND-IUC	India	**Majumdar, Suman**	IIT Indore	PI
IND-IUC	India	**Mishra, Preetish**	IUCAA	JA
IND-IUC	India	**Mitra, Ayan**	IUCAA	JA
IND-IUC	India	**More, Anupreeta**	IUCAA	PI
IND-IUC	India	**More, Surhud**	IUCAA	PI
IND-IUC	India	**Ratewal, Amit Kumar**	IUCAA	JA
IND-IUC	India	**Raychaudhury, Somak**	IUCAA	PI
IND-IUC	India	**Saha, Kanak**	IUCAA	PI
IND-IUC	India	**Shukla, Amit**	IIT Indore	PI
IND-IUC	India	**Smitha, Subramanian**	IIA	PI
IND-IUC	India	**Sutaria, Firoza**	IIA	PI
IND-IUC	India	**Swain, Vishwajeet**	IIT Bombay	JA
IND-IUC	India	**Vaidya, Bhargav**	IIT Indore	PI
IND-IUC	India	**Wadadekar, Yogesh**	NCRA-TIFR	PI

For more information

Rubin/LSST website: www.lsst.org
Galaxies Science consortium: sites.google.com/view/lsstgsc