Stellar Population Properties and Star formation Histories of Galaxies in ~6 billion years old Universe

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Seminar Talk

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MOTIVATIONS

- Present-day galaxies are **mostly dead**: Star Formation occurred in the distant past and it is difficult to resolve SFH from integrated spectra.
- We do not know what processes drive/shut-off the star-formation in galaxies.
- z~1 intermediate redshift studies can connect dots about galaxy evolution.
- Multi-variate correlations exist between galaxy’s stellar population properties and its structure, size, nuclear activity and environment
- Universal Bimodality of Galaxies

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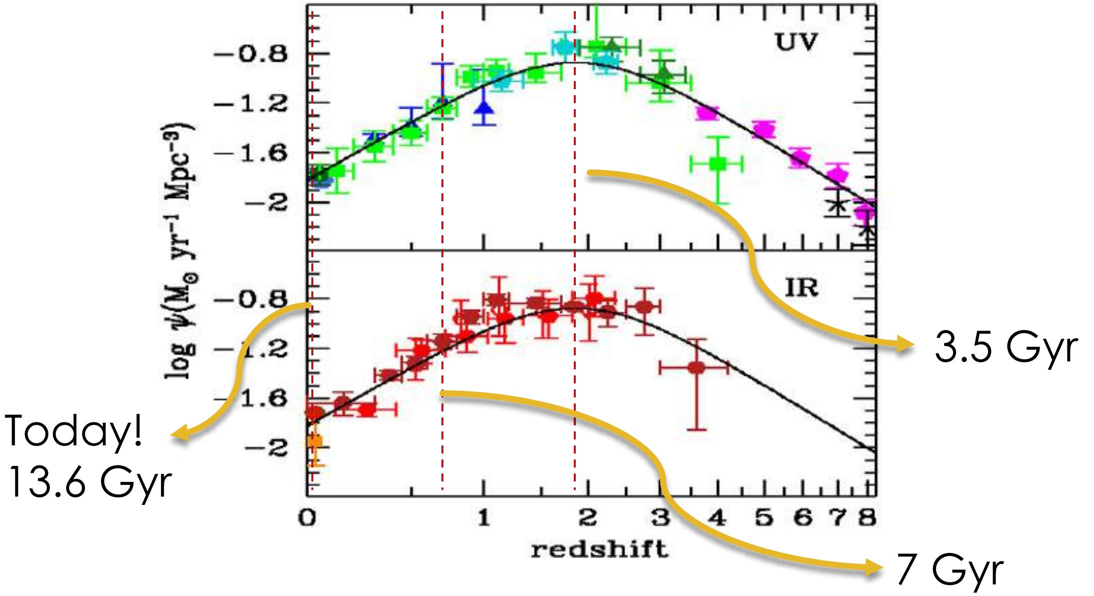


Fig 1 : SFRD peaks around z ~2 from Madau and Dickinson 2014

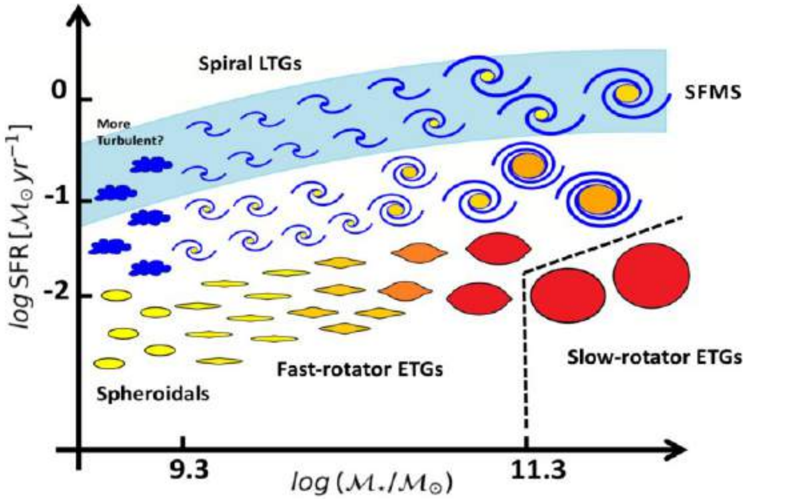
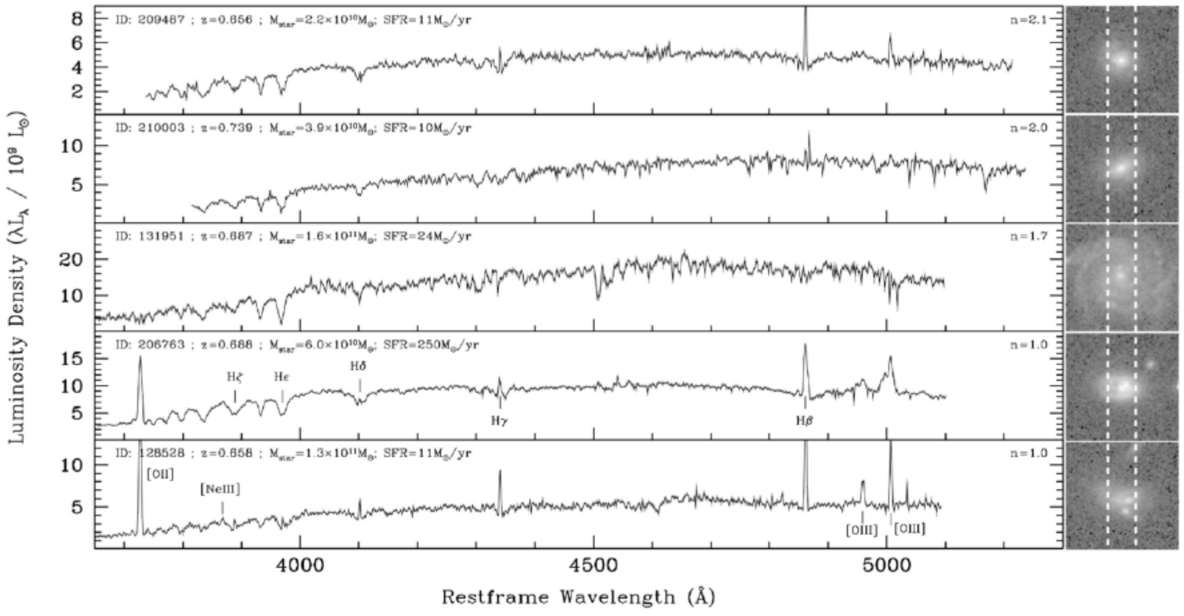
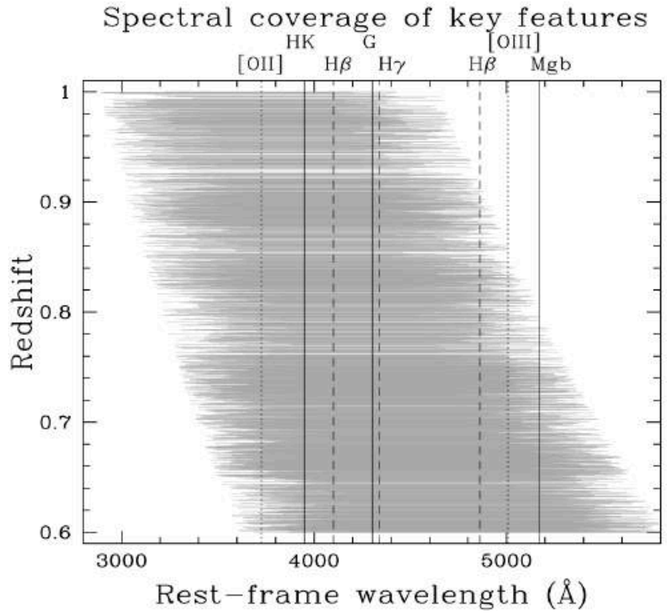


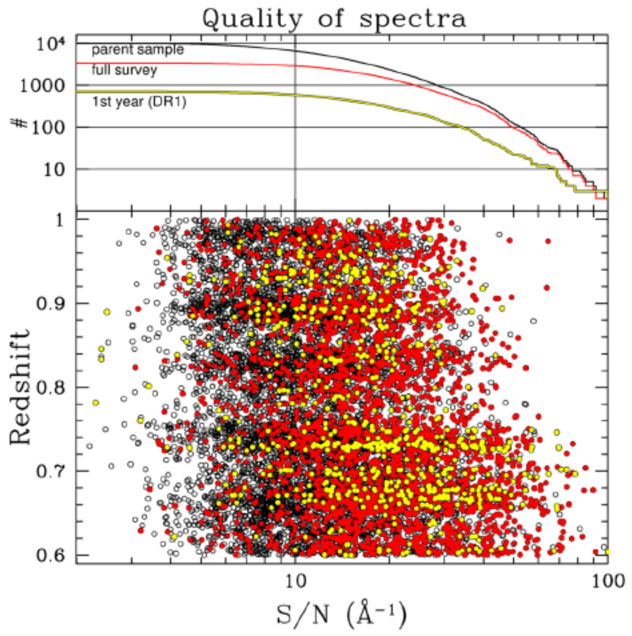
Fig 2 : SDSS-Manga IV study from Wang et al 2020 showing relation between local galaxy properties and morphology

LEGA-C Dataset Highlights

- VLT-ViMOS spectroscopic survey of galaxies in $0.6 < z < 1.0$ covering 1.3 sq degrees in COSMOS field
- ~3200 K-band selected galaxies ($K < 20.7 - 7.5 \times \log((1 + z)/1.8)$)
- ~20 hours per object, S/N > 10 Å^{-1} , wavelength range ~ 3000 Å −6000 Å , 0.6 Å wavelength resolution
- Accurate measurements of absorption and emission line strengths, widths and ratios.



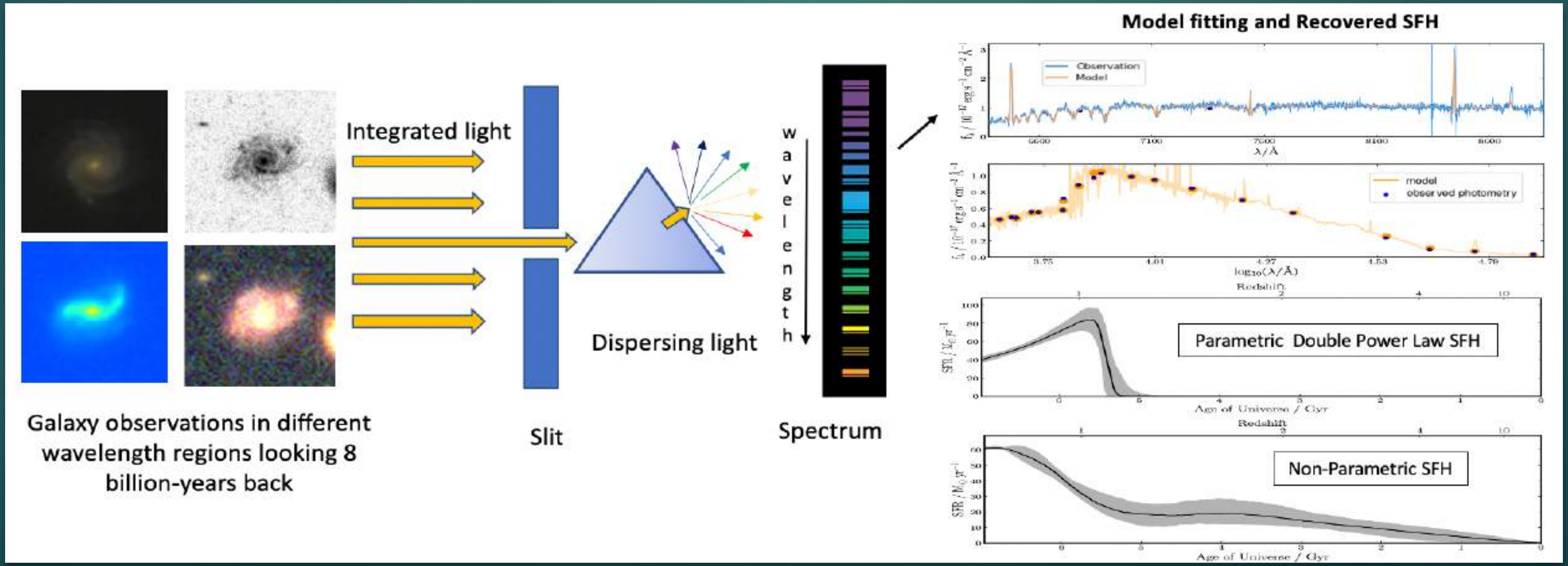




Survey Scientist- Dr. Rachel Bezanson

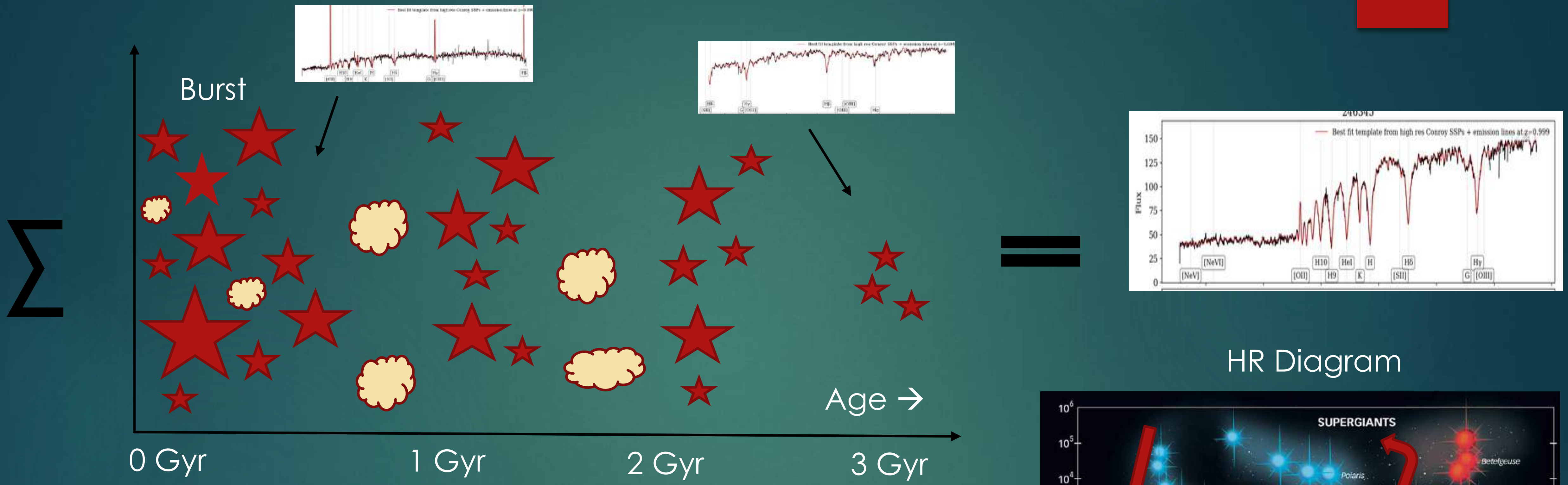
GOALS

- Use deep continuum spectroscopy to trace the history of star formation, mass accumulation and chemical composition of these galaxies.
- Statistically study the interplay between population parameters, environment and star formation histories of the early universe galaxies
- Connecting the progenitors (past galaxies) to descendants (present galaxies)
- Break the age-metallicity-dust degeneracy and quantify these parameters for each galaxy in the sample

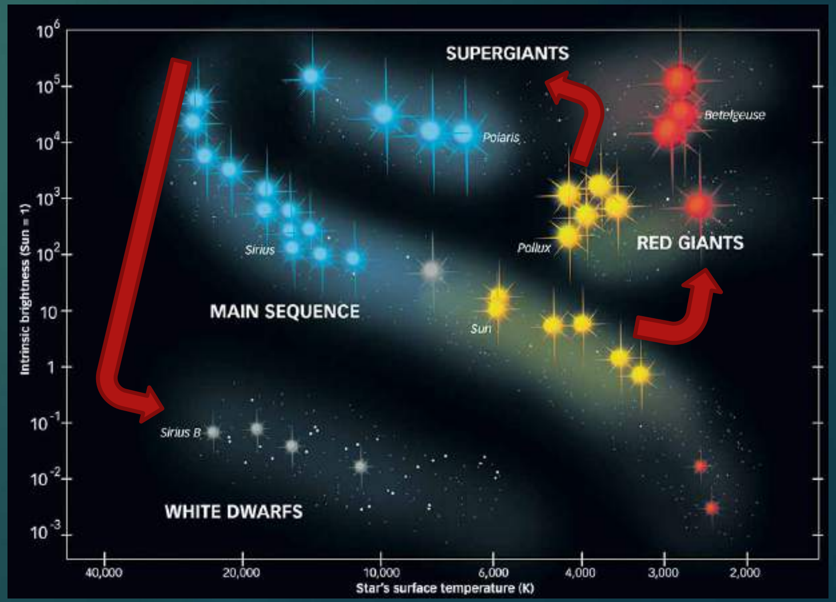


How to extract information from the spectrum?

MODELS: SSPs, CSPs AND STELLAR POPULATION SYNTHESIS



HR Diagram

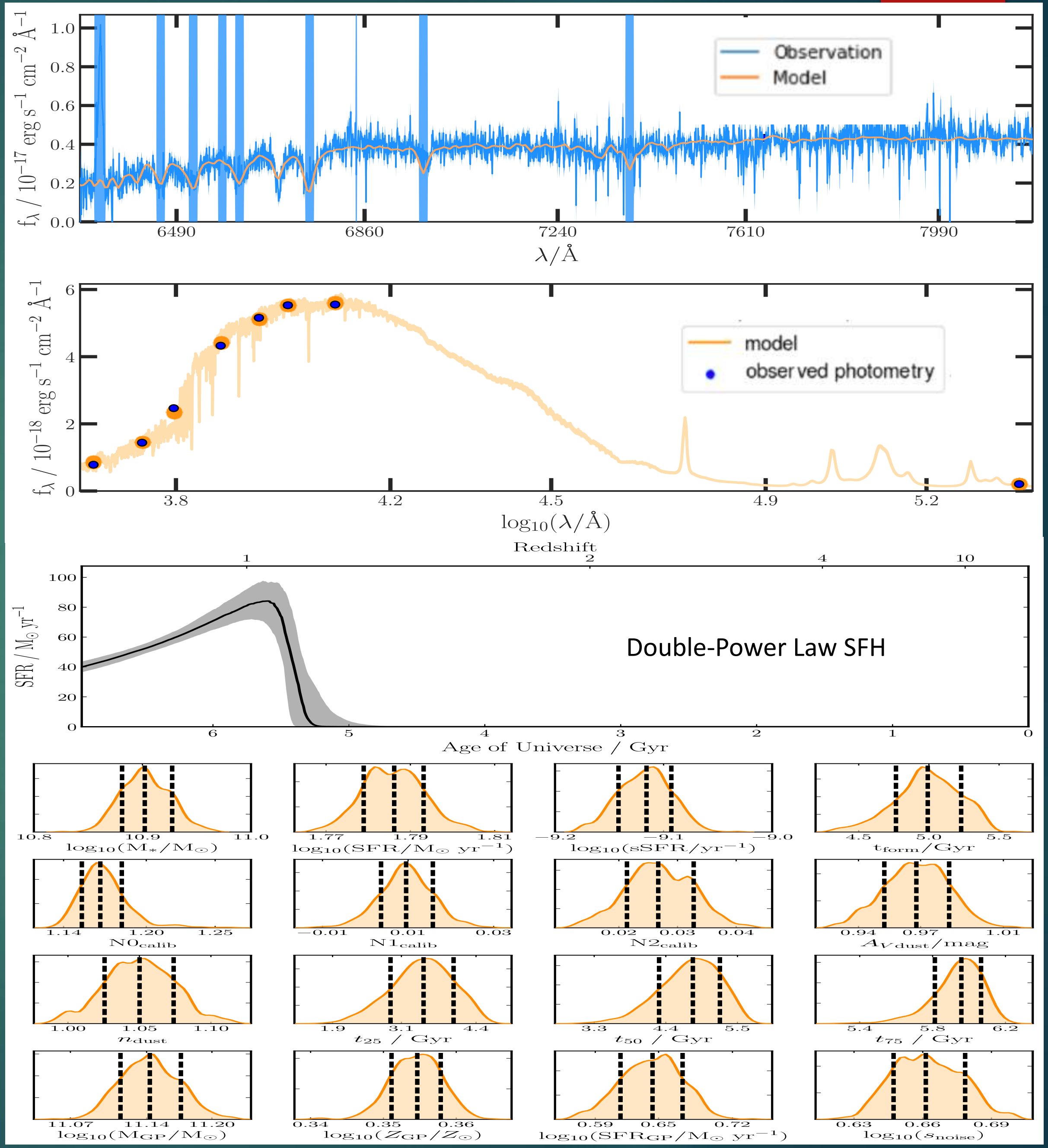


- SSP : All stars formed in a burst
- Stellar evolution tracks → T_0 , L_0 for various M_* with time
- Σ Stellar templates → weighted by IMF + Dust + Chemical Enrichment → single-age populations as a function of age.
- Σ Isochrones (linear combination) → spectrum/colors of a galaxy with an arbitrary SFH

Bagpipes

(Bayesian Analysis of Galaxies for Physical Inference and Parameter Estimation)

- Parametric Bayesian SED and Spectral fitting tool
- MultiNest Nested Sampling Algorithm
- Posterior distributions of Age, M_* , Z_*, SFH, A_V and σ_*
- IMF: Kroupa & Boily 2002
- BC03 (2016) SSP Models



Bagpipes Parametrizations

Star Formation History

- Exponential
- Delayed Exponential
- Lognormal
- Double Power Law (Most Flexible)
- Bursts (A,M,Z) can be added

Dust Laws

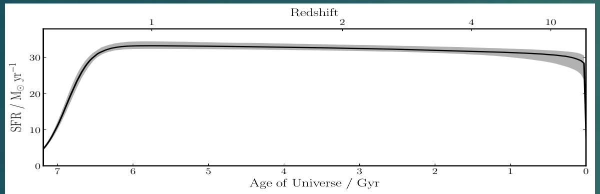
- CF00 (Av, n)
- Salim (Av, n, δ, B)
- Calzetti (local SF)
- Cardelli (MW dust)

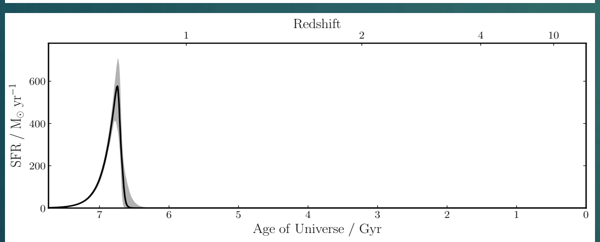
Priors

- Uniform
- Log_{10}
- Log
- Power of 10
- Reciprocal
- Gaussian

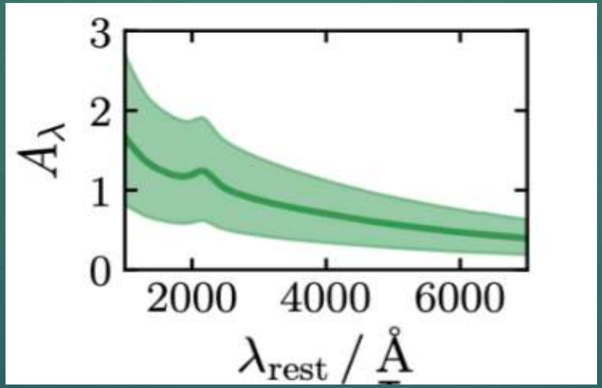
Spectral Noise

- White noise
- Gaussian correlated noise

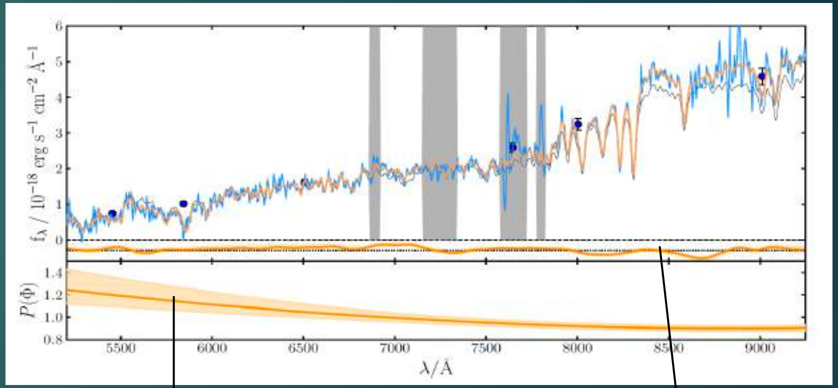




$$\mathrm{SFR}(t) \propto \left[\left(\frac{t}{\tau}\right)^{\alpha} + \left(\frac{t}{\tau}\right)^{-\beta}\right]^{-1},$$



$$\log_{10}\left(T^0(a_i,\lambda)\right) = \begin{cases} -\dfrac{0.4\,\epsilon\, A_V\, k(\lambda)}{R_V} & a_i < a_{\mathrm{BC}} \\ -\dfrac{0.4\, A_V\, k(\lambda)}{R_V} & a_i > a_{\mathrm{BC}} \end{cases}$$



Calibration

Gaussian-process noise

Carnall+2019 et al

Caveat!

Computationally Expensive: Cluster Proposal

- ~450 CPU hours/galaxy per SFH required
- Proposal approved for 3.5 million CPU hours
- ~ 1 month to fit full data-set (max. 96 nodes each with 28-cores available)
- 14 nodes (392 cores) can be used simultaneously with close to ideal Speedup for 400 live sampling points.

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Finding light eight billion years old

Astronomy is often called the first science. Considering that early humans also made tools and controlled fire, engineers and chemists may disagree. Whether or not astronomy is the first science, Rachel Bezanson is convinced of one thing: "Astronomy is the coolest science." Bezanson, assistant professor of physics and astronomy, uses CRC resources to analyze large data sets from an international astronomical survey to help answer a fundamental question reaching back to the beginning of the universe – how do galaxies form?

The Very Large Telescope of the European Southern Observatory in the Atacama Desert, northern Chile.

The Atacama Desert in northern Chile is one of the driest places on earth; some areas receive no form of precipitation for years at a time. With no cloud cover and little human habitation, the Atacama is a perfect area for astronomical observatories. Since 2014, Bezanson has spent two weeks at a time in the Atacama working on the Very Large Telescope of the European Southern Observatory as the survey scientist on the Large Early Galaxy Astrophysics Census (LEGA-C), an astronomical survey that has collected high resolution electromagnetic spectra of several thousand galaxies on time scales stretching back eight billion years. Before LEGA-C, spectra were only available for galaxies in the nearby universe, looking back less than one billion years.

The LEGA-C survey spent 130 nights gathering spectra of some 3,200 galaxies – galaxies so far away that the light from their stars has traveled for half the age of the universe to reach earth. The survey was recently completed, and the complete dataset will soon be publicly available.

"We spent nearly six months of nights working on one of the largest telescopes in the world," says Bezanson, "We looked at galaxies so distant that the light has been traveling toward us for half the age of the universe."

Bezanson studies the evolution of the oldest and most massive galaxies – how evolving stars assemble to form galaxies, and what causes that evolution to end.

"The spectra are windows into what galaxies were at the beginning," she explains. "Snapshots. We connect the dots much like archeologists – one bone from one epoch, one bone from another."

"Using the Very Large Telescope we were able to focus on individual galaxies in tiny patches of the sky, collecting details about how bright a galaxy is at a given wavelength based on the signature emission patterns of elements, and how stars move within galaxies based on measuring redshifts on the Doppler spectrum. We are looking primarily for clues to the average ages of the galaxies, whether they experienced rapid or extended formations, and the effects of dynamical masses derived from stellar velocity dispersions – in other words, motions of stars in the expanding early universe."

To analyze the data, Bezanson's team applies sophisticated modeling techniques using CRC resources. Graduate student Yasha Kaushal works in collaboration with CRC with a state-of-the-art Python statistical modeling package called BAGPIPES (Bayesian Analysis of Galaxies for Physical

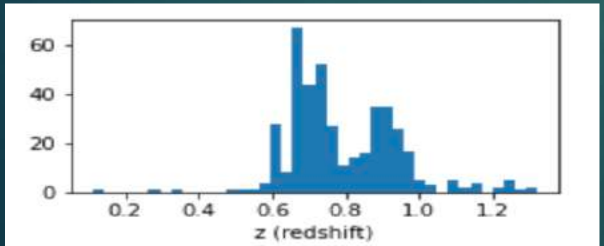
https://crc.pitt.edu/Finding-Light-Eight-Billion-Years-Old/

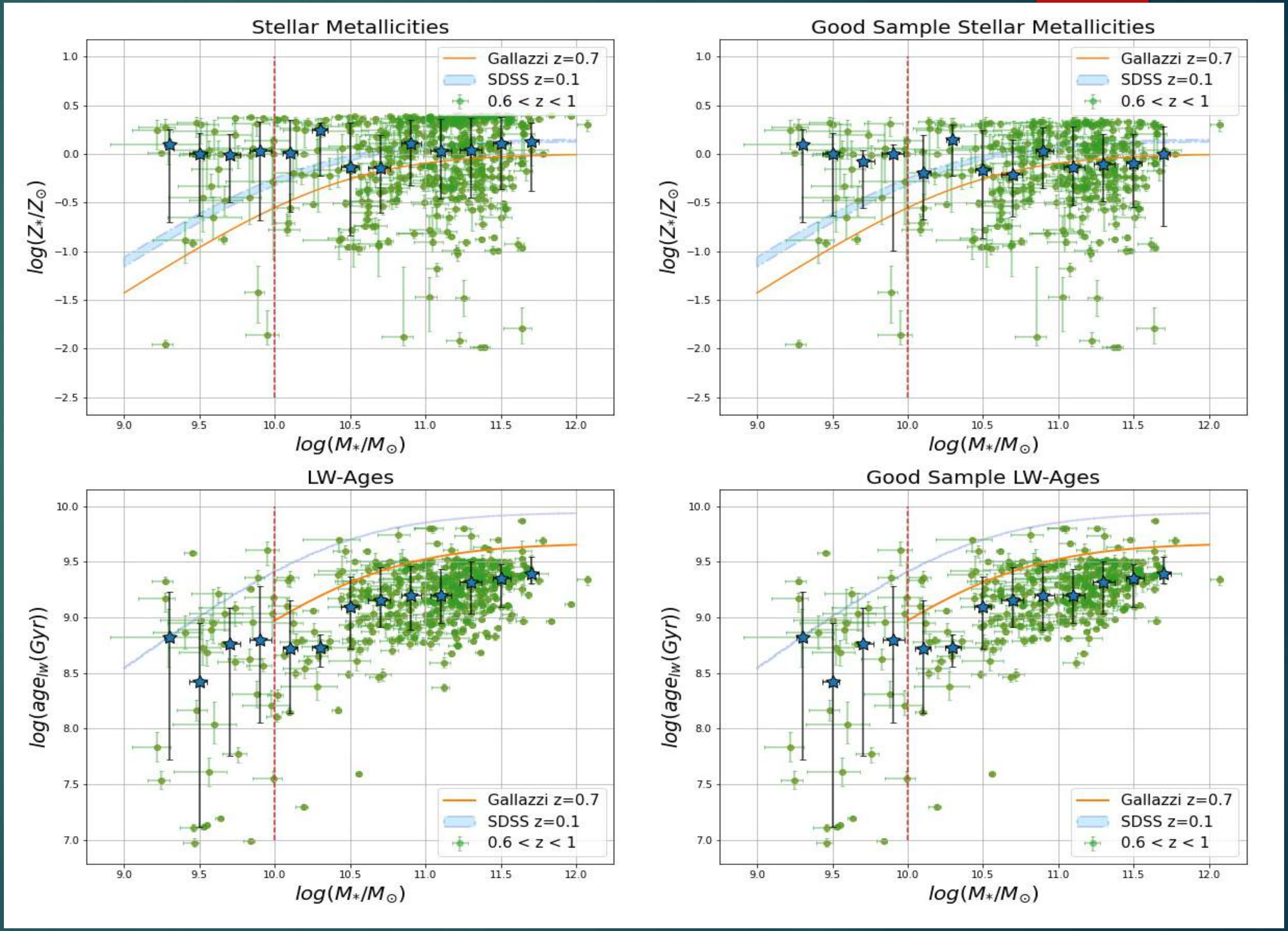
Initial Results- Stellar Metallicities and Light Weighted Ages

Our Sample -
LEGA-C in Cosmos Field
0.6 < z < 1
420 Galaxies
~ 130 Q
~ 290 SF

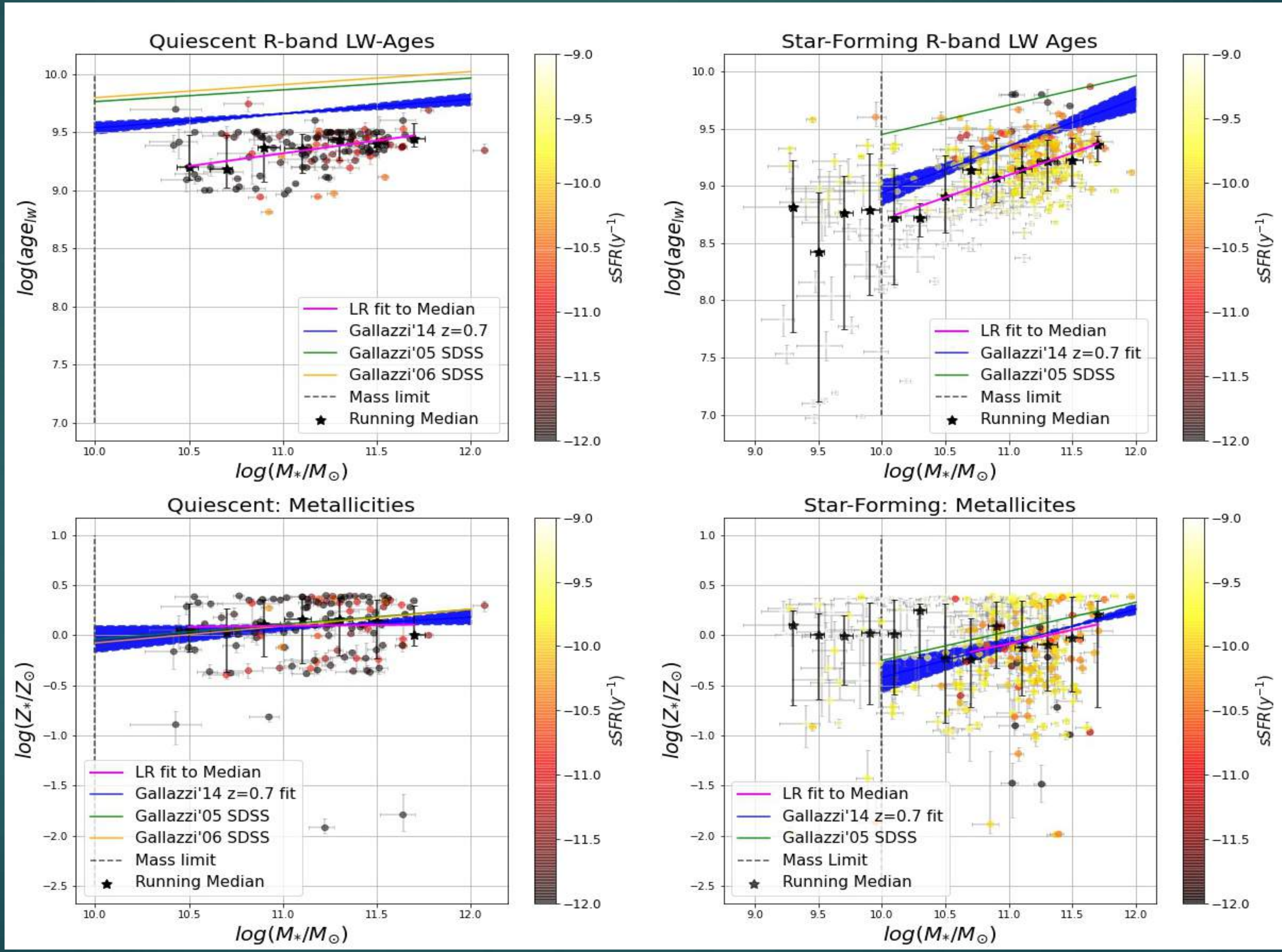
Gallazzi's Sample -
Extended Chandra Deep Field South survey
0.65 < z < 0.75
71 Galaxies
~ 30 Q
~ 40 SF

Our
Redshift Distribution



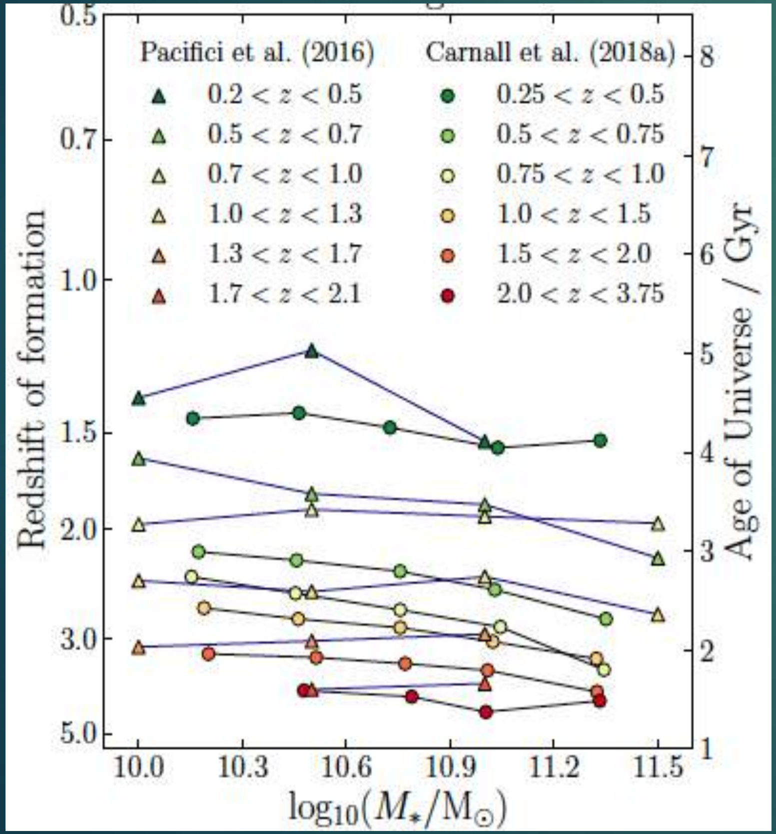


Initial Results-
Q+SF trends with sSFR



Initial Results-
Formation times with Stellar Mass for different redshifts

Adam + 2019
Massive Quiescents



t_{form} ?
t_{quech}?
τ_{quench}?
Feedbacks?
Early/Late quenching?
Fast Slow quenching?

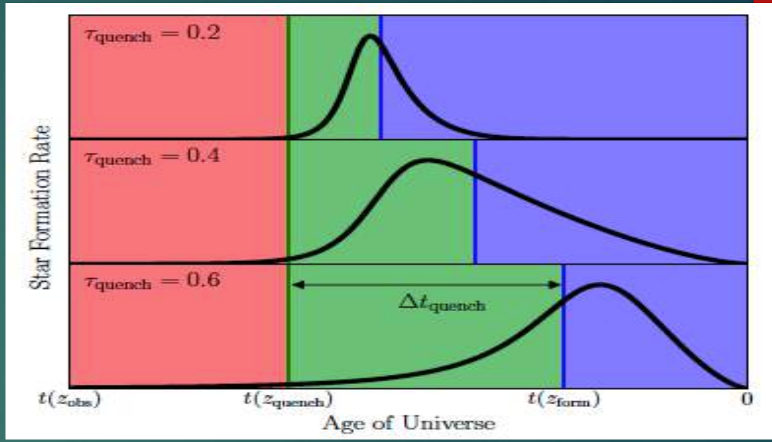
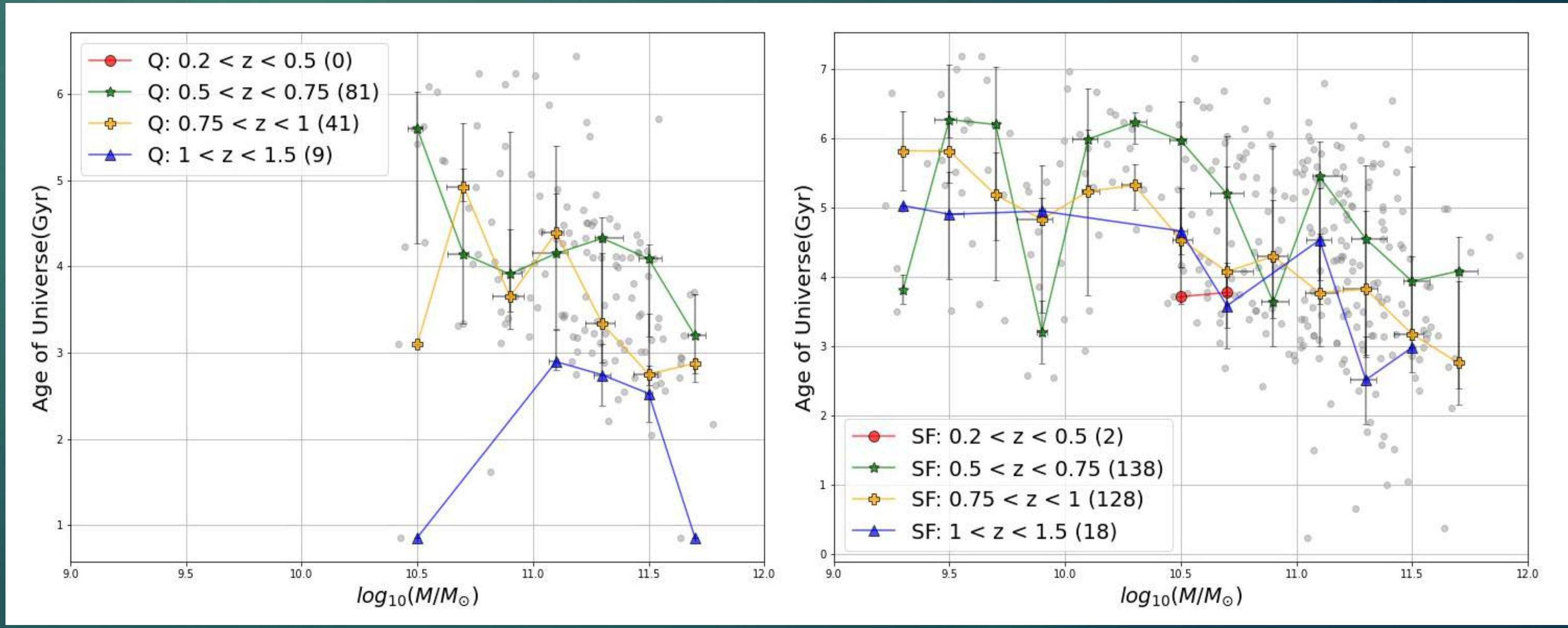


Fig 6
Adam + 2017

Our Sample



Conclusions and Future Work

- At any epoch of time, less-massive galaxies are found to have younger stellar populations than their more massive counterparts (Downsizing)
- More heavy metal chemical enrichment for massive galaxies than lower mass ones
- At a fixed stellar mass, a trend towards *lower* average formation redshift is found with *decreasing* observed redshift

  Reasons : 1. New galaxies joining the red sequence

  2. Mergers

  3. periods of rejuvenated star-formation activity
- Present full data results at STScI MOS conference in May.
- Perform Non-parametric SFH modeling with *Prospector* in collaboration with Joel Leja (Penn State) this summer.
- Extend the analysis to MOSDEF galaxies in $1.7 < z < 2$ with Mariska Kriek (UC Berkley)

Thank you!