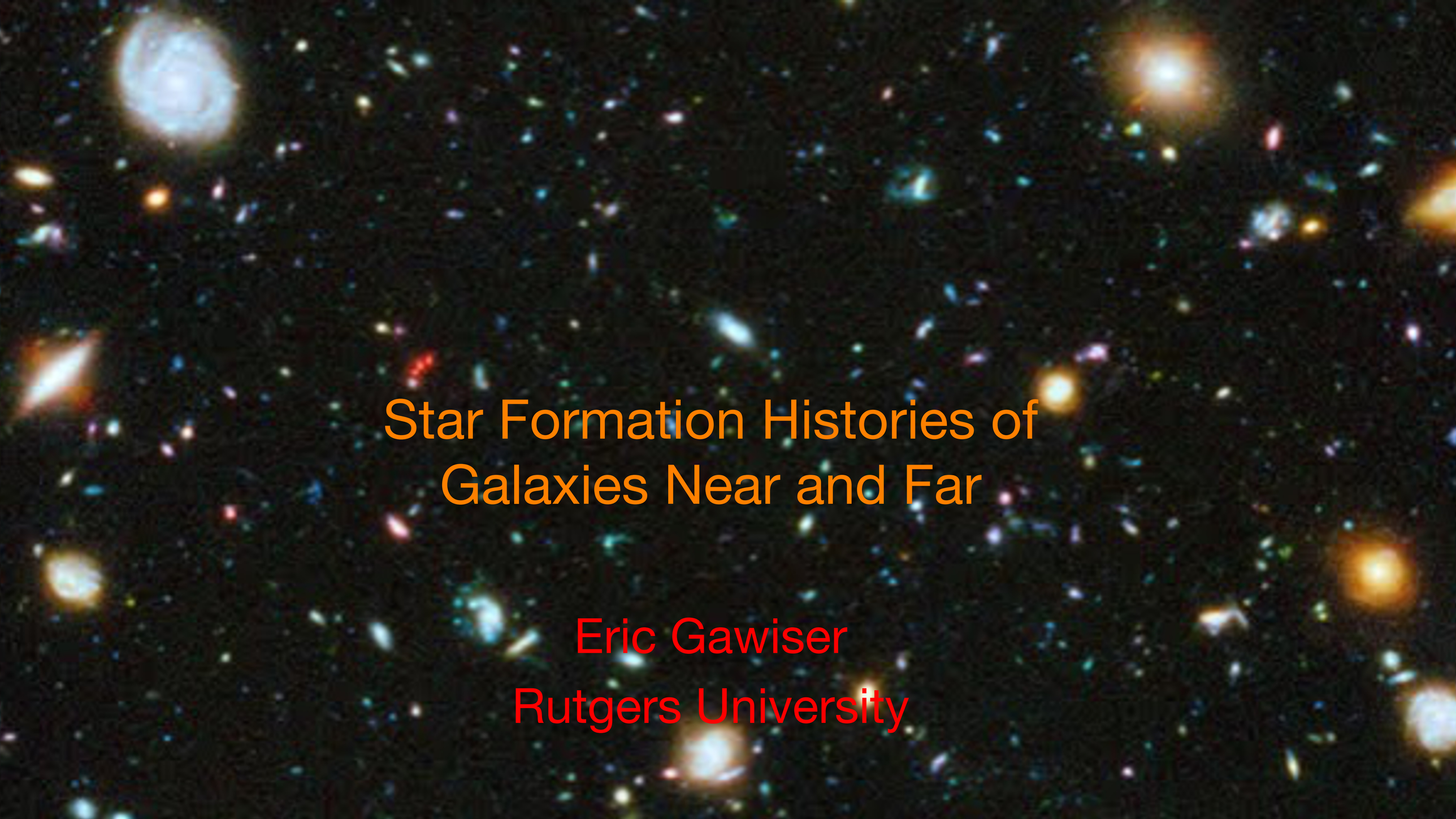


# Star Formation Histories of Galaxies Near and Far

Eric Gawiser
Rutgers University

# Conclusions

- Careful analysis of galaxy Spectral Energy Distributions allows us to reconstruct their star formation histories, which are a powerful tool for probing galaxy evolution.
- Looking at correlations between Local Volume dwarf galaxies, we found synchronized star formation features at ~3 and ~6 Gyr lookback time.
- Using the SFHs of Local Group and Local Volume galaxies, we found signs of conformity that were independent of synchronized star formation.
- ODIN is using DECam to obtain unprecedented samples of LAEs, LABs, and protoclusters in 7 well-studied fields.
- ODIN Early Science involves state-of-the-art analyses of the spatial clustering of these objects, including cross-correlations, as well as LAE star formation histories.

# Cast: Gawiser Research Group

George Kharchilava

Nicole Firestone

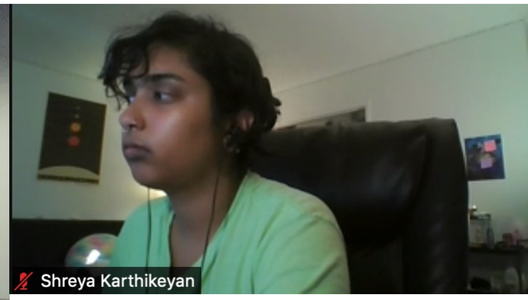
Irene Moskowitz

Charlotte Olsen

Heather Prince

Rameen Farooq

Shreya Karthikeyan

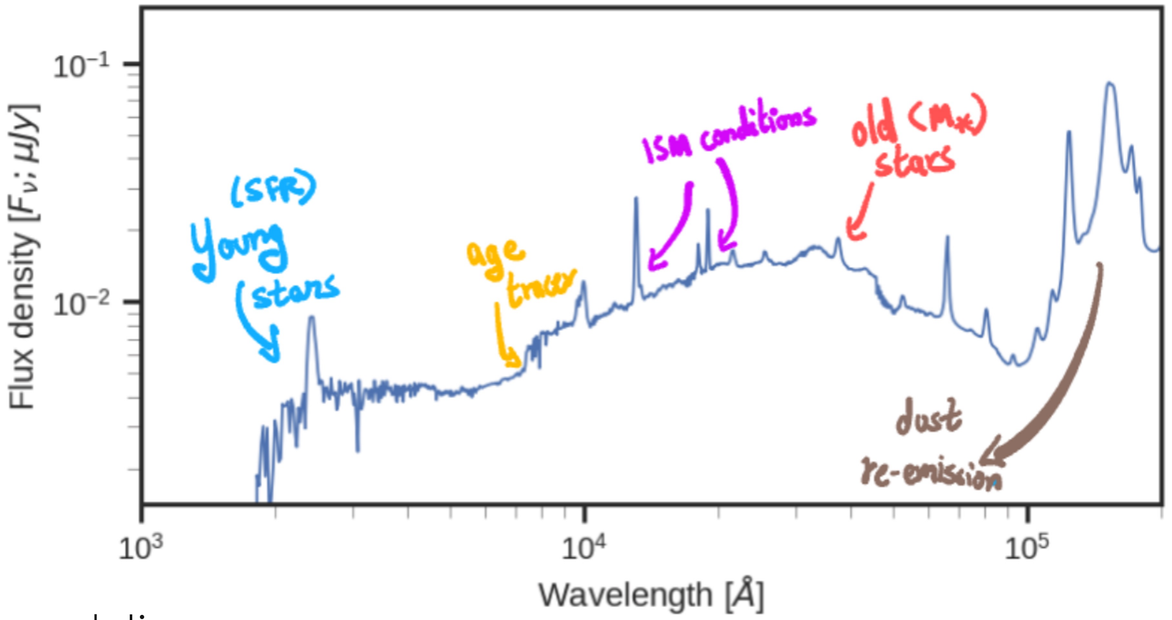



(REU student, U. Maryland)

# Spectral Energy Distribution (SED) fitting

The integrated light from galaxies contains a lot of information about their present and past.

- Redshift (z)
- Stellar mass ($M_*$)
- Star Formation Rate (SFR)
- Chemical abundances (stars and gas)
- Dust properties

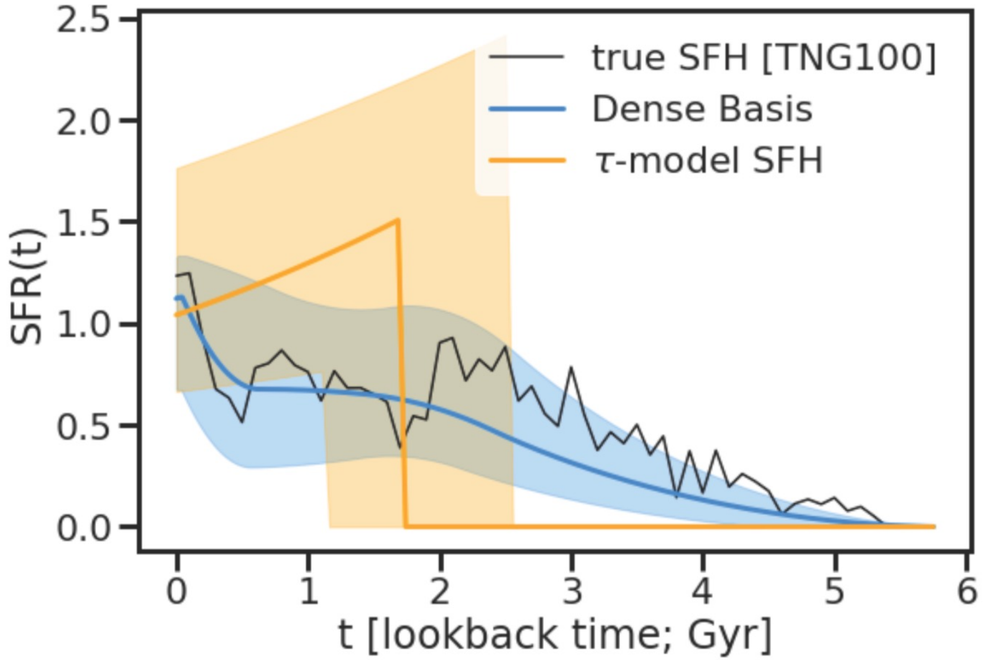



We infer these properties by forward-modeling SEDs using stellar population synthesis models (stellar tracks and isochrones)

Slide from Kartheik Iyer

# Spectral Energy Distribution (SED) fitting

Traditionally, assumed simplistic Star Formation Histories – instantaneous rise followed by constant or exponential decline

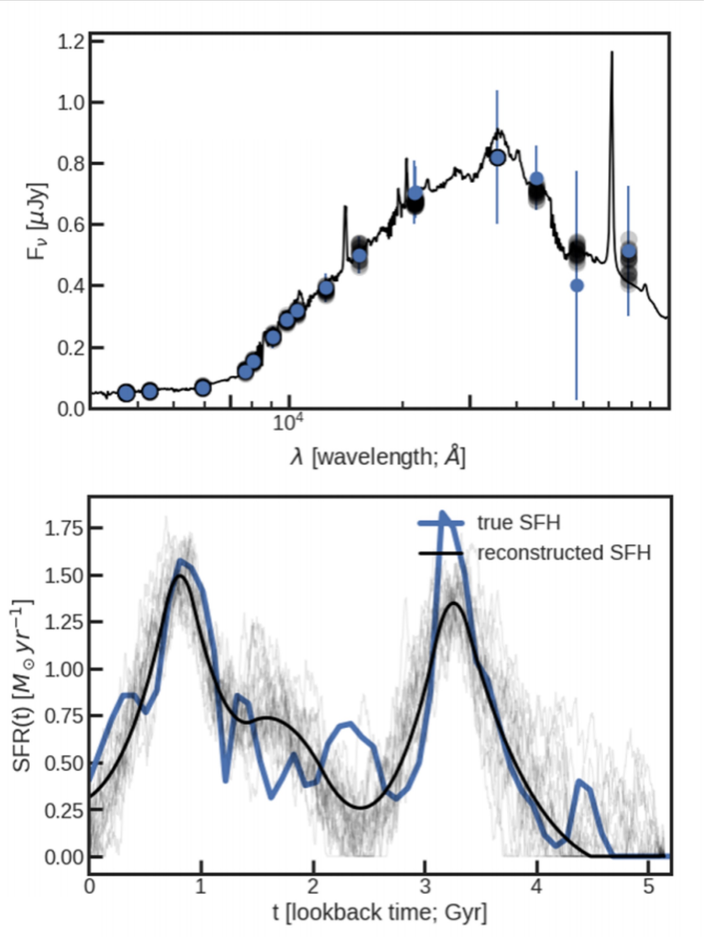



Seek physical, non-parametric SFHs i.e., smooth curves where the number of features increases with the data quality

Achieved by Gaussian Process ``Dense Basis'' method (Iyer+19, see also Gawiser & Iyer 17)

Other approaches with flexible SFHs: Pacifici+12, Leja+19 (Prospector), Robotham+20 (ProSpect)

# **Dense Basis** Star Formation History (SFH) reconstruction




-- must be physically motivated

*(eg. SFR can't go negative or have discontinuous derivatives)*

- encode the maximal amount of information with a minimal number of parameters

- correspondence between goodness-of-fit in Spectral Energy Distribution space and goodness-of-reconstruction in SFH space

Iyer & Gawiser 17, ApJ 838 127

# **Dense Basis**:
## A flexible parameterization in ($t_x$)

- Describe Star Formation History with a tuple: **($M_*$, SFR, [$t_x$])** - lookback times at which a galaxy formed different fractions of its stellar mass.

- **Gaussian Processes** allow us to create smooth SFHs that satisfy these integral constraints.

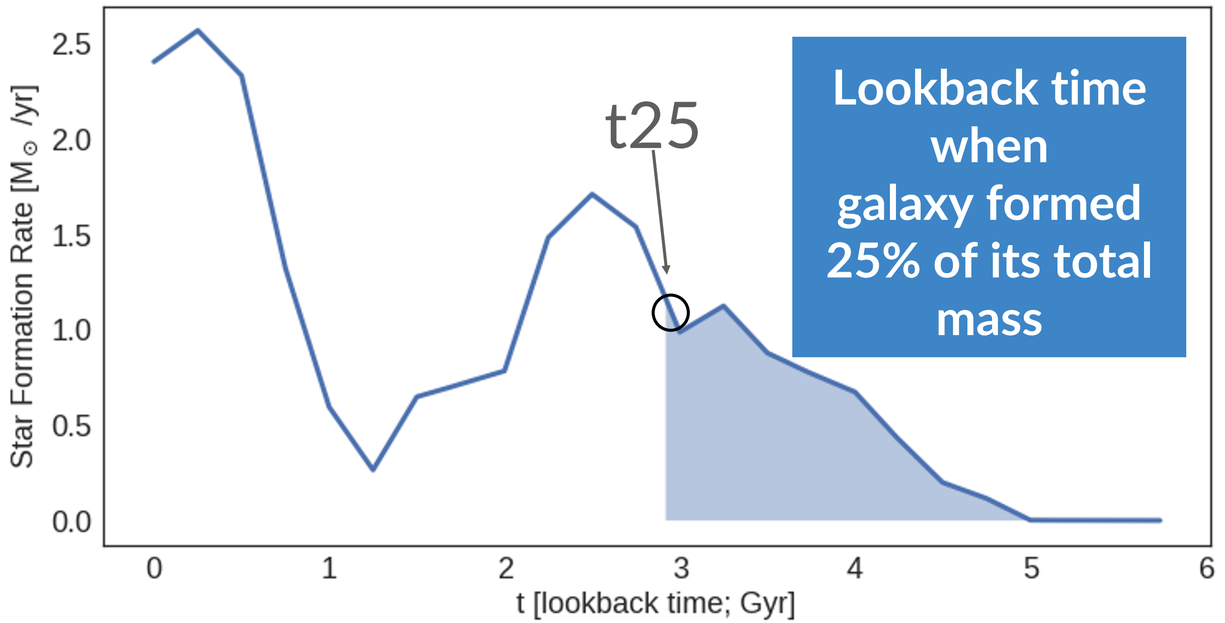
- A **flexible number of parameters** allows us to specify the SFH to arbitrary precision, making this approach **non-parametric**

- Can be incorporated into any SED fitting code (although the default Dense Basis code is parallelized and extremely fast – available at github.com/kartheikiyer )

Slide from Kartheik Iyer

**Dense Basis**:
A flexible parameterization in (tx)

Describe SFH with a tuple: ($M_*$, SFR, [tx])




SFH from Somerville+15 semi-analytic model

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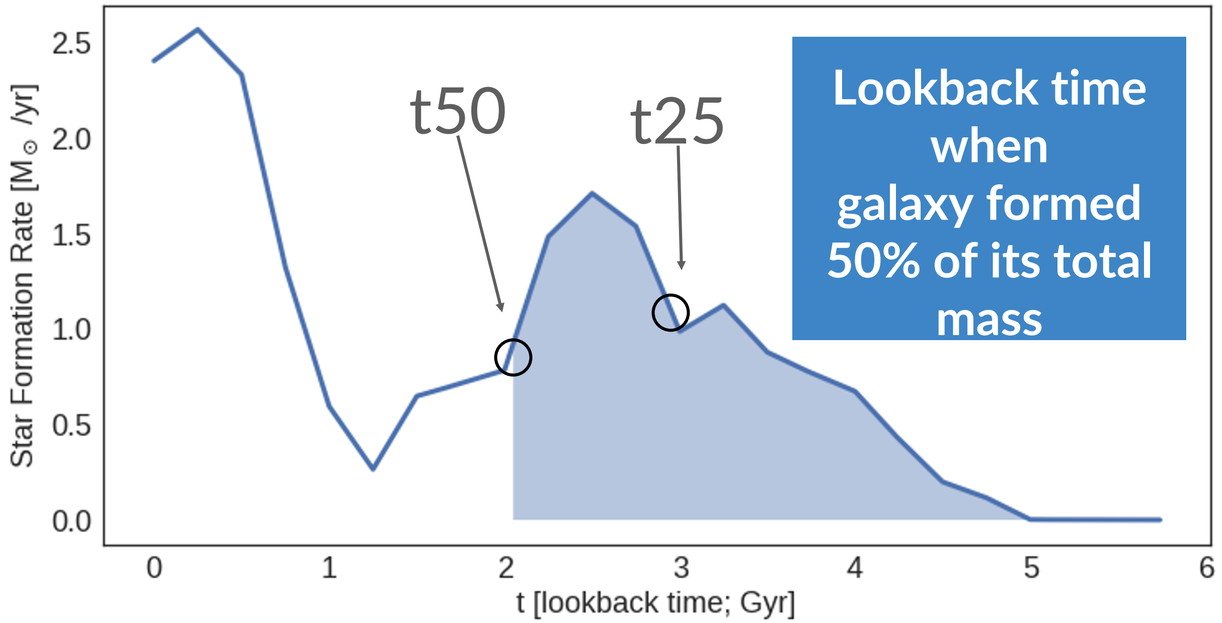


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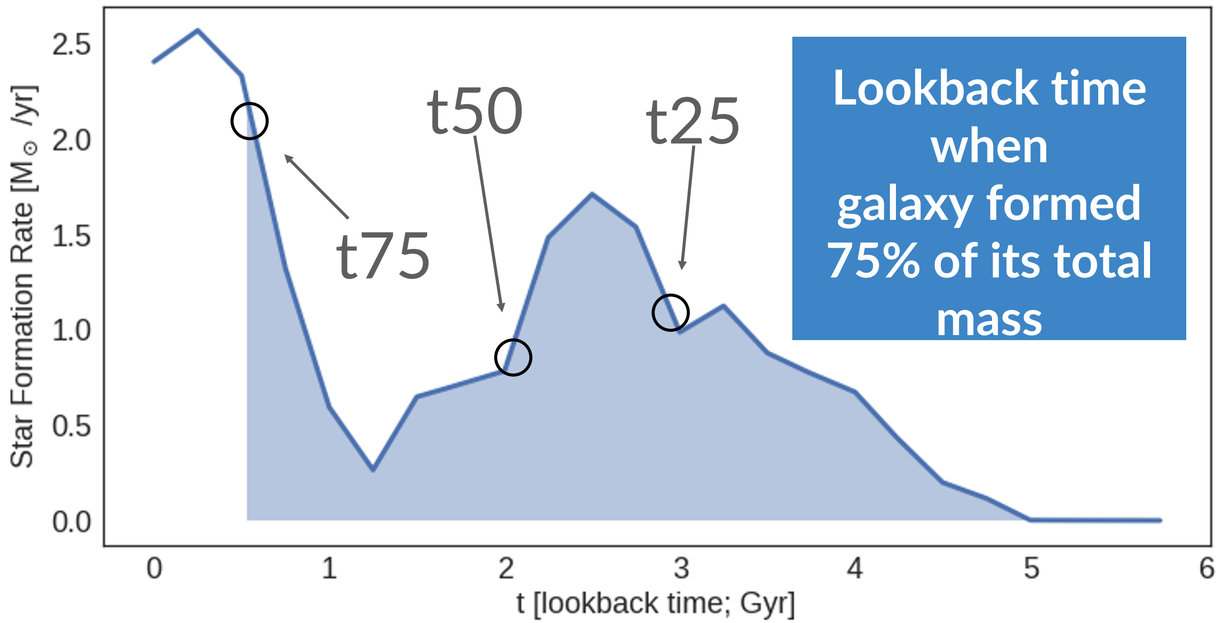


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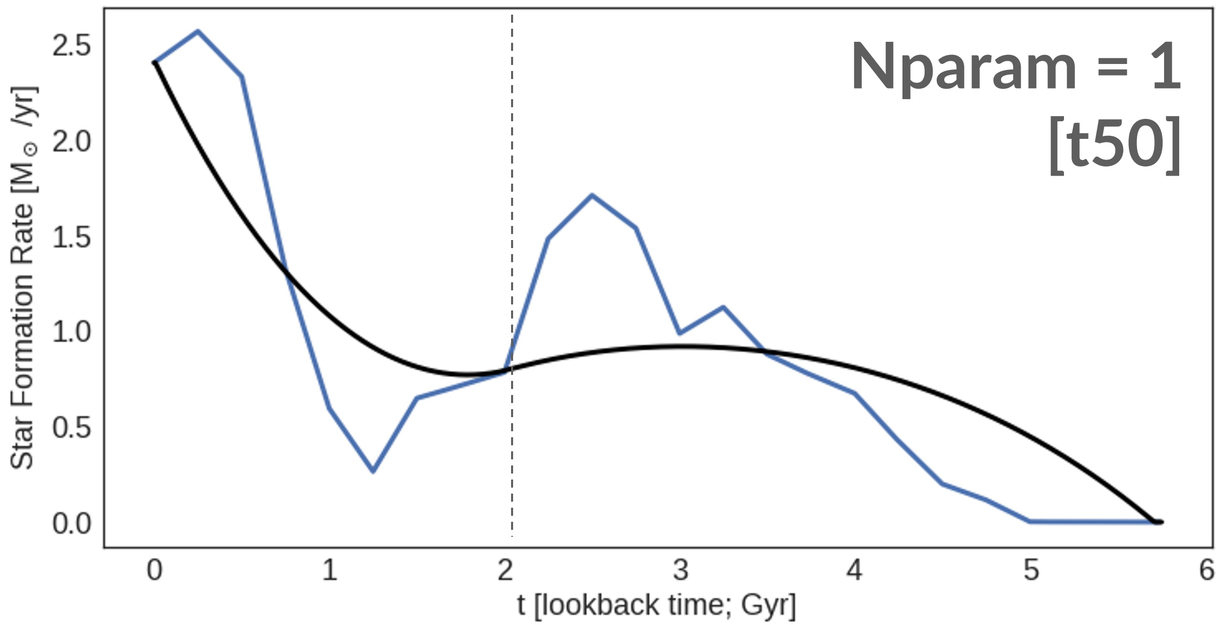


Iyer et al. 19, ApJ 879, 116

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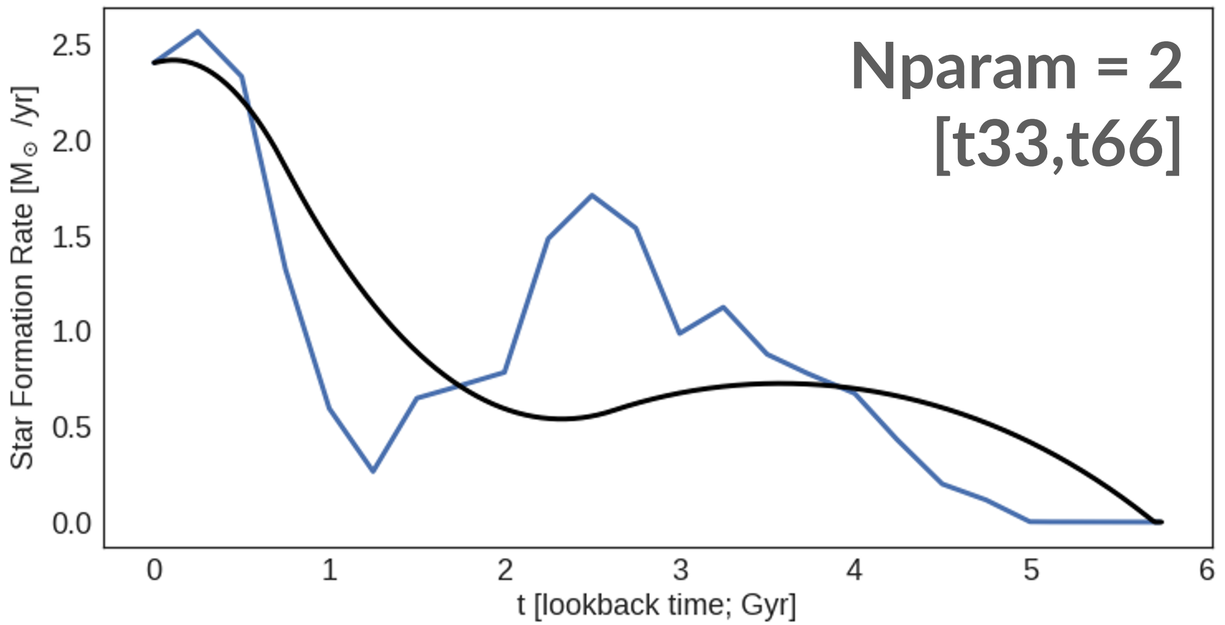


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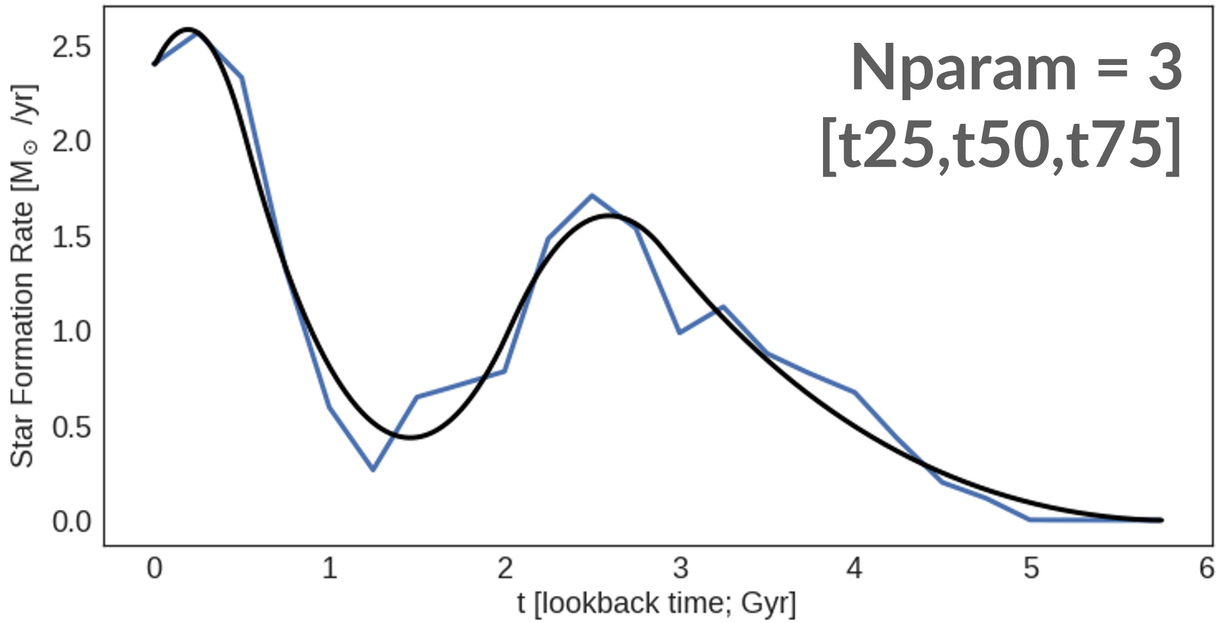


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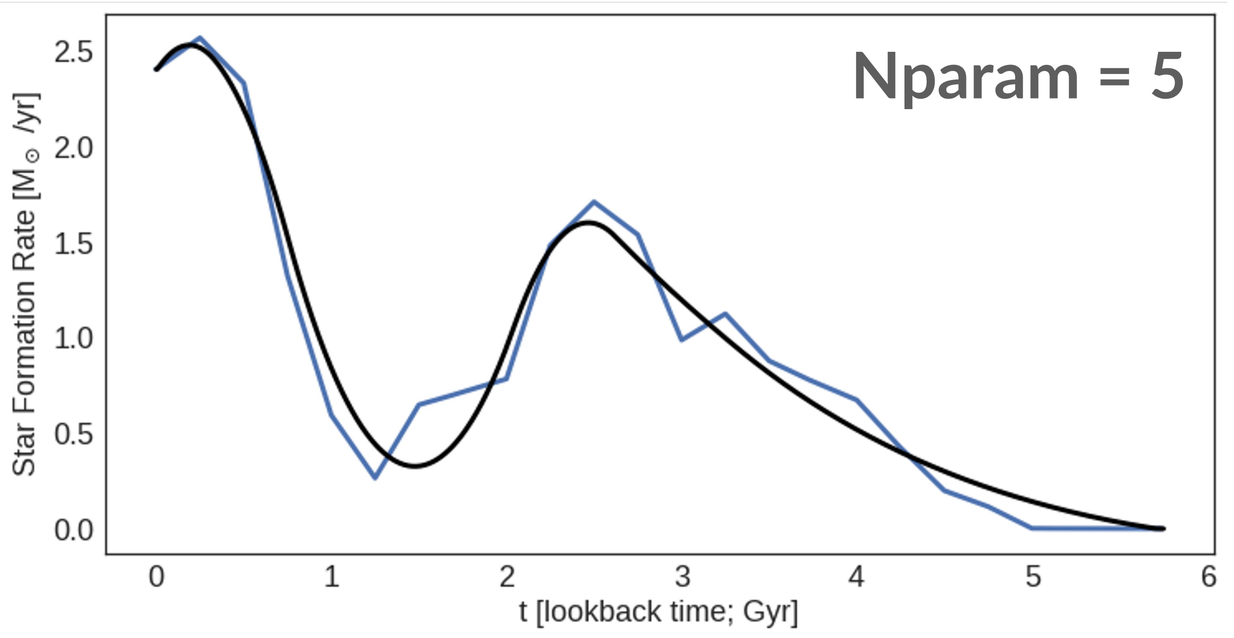
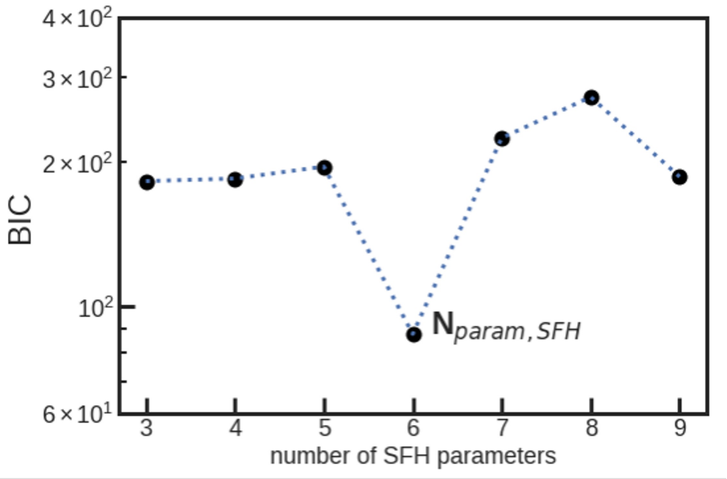



Iyer et al. 19, ApJ 879, 116

**Dense Basis**:
Describe SFH with a tuple:
($M_*$, SFR, [tx])

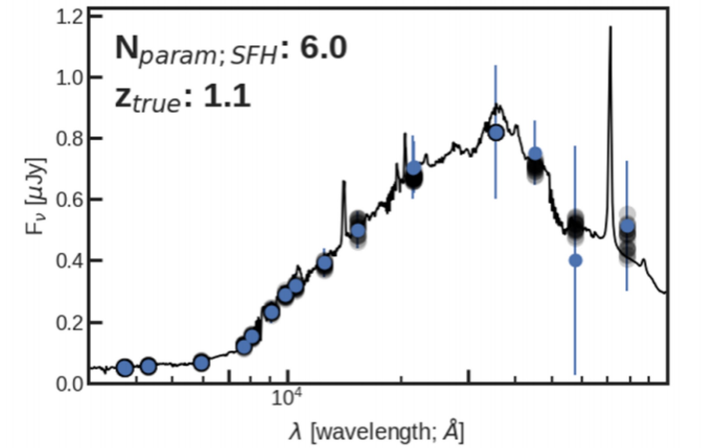
Find an optimal number of SFH parameters for each SED being fit using appropriate model selection criterion.

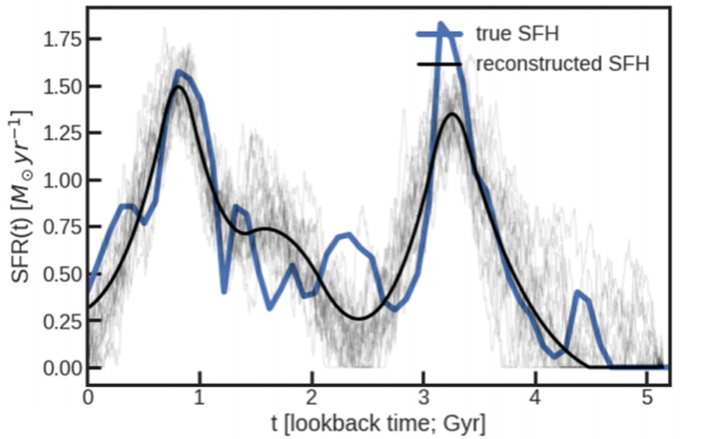



Iyer et al. 19, ApJ 879, 116

**Dense Basis**:
Describe SFH with a tuple:
(M∗, SFR, [tx])

In Spectral Energy Distribution space, fit for SFH parameters simultaneously with models for dust, metallicity, redshift, nebular emission, intergalactic medium absorption, etc.




**Full posteriors**

Iyer et al. 19, ApJ 879, 116

What do these **SFHs** tell us
about galaxies (and how they evolve)?

- more **robust SFR, $M_*$**, {tx} and related estimates.

- the number & **duration of major episodes of star formation** in a galaxy's past.

- the **evolution of scaling relations** like the SFR-$M_*$ correlation.

- the **timescales of morphological transformations**.

- the **stochasticity timescale** of an ensemble of galaxies.

- **constraints on feedback processes** that regulate SF (through comparisons with simulations).

# Recent discovery enabled by Dense Basis star formation history reconstruction:

**Star Formation Histories from Spectral Energy Distributions and Color Magnitude Diagrams Agree: Evidence for Synchronized Star Formation in Local Volume Dwarf Galaxies over the Past 3 Gyrs**


Charlotte Olsen

Advisor: Prof. Eric Gawiser

Rutgers University, New Brunswick, NJ



THE ASTROPHYSICAL JOURNAL


Star Formation Histories from Spectral Energy Distributions and Color–magnitude Diagrams Agree: Evidence for Synchronized Star Formation in Local Volume Dwarf Galaxies over the Past 3 Gyr


Charlotte Olsen[1], Eric Gawiser[1], Kartheik Iyer[2], Kristen B. W. McQuinn[1], Benjamin D. Johnson[3], Grace Telford[1], Anna C. Wright[4], Adam Broussard[1], and Peter Kurczynski[5]



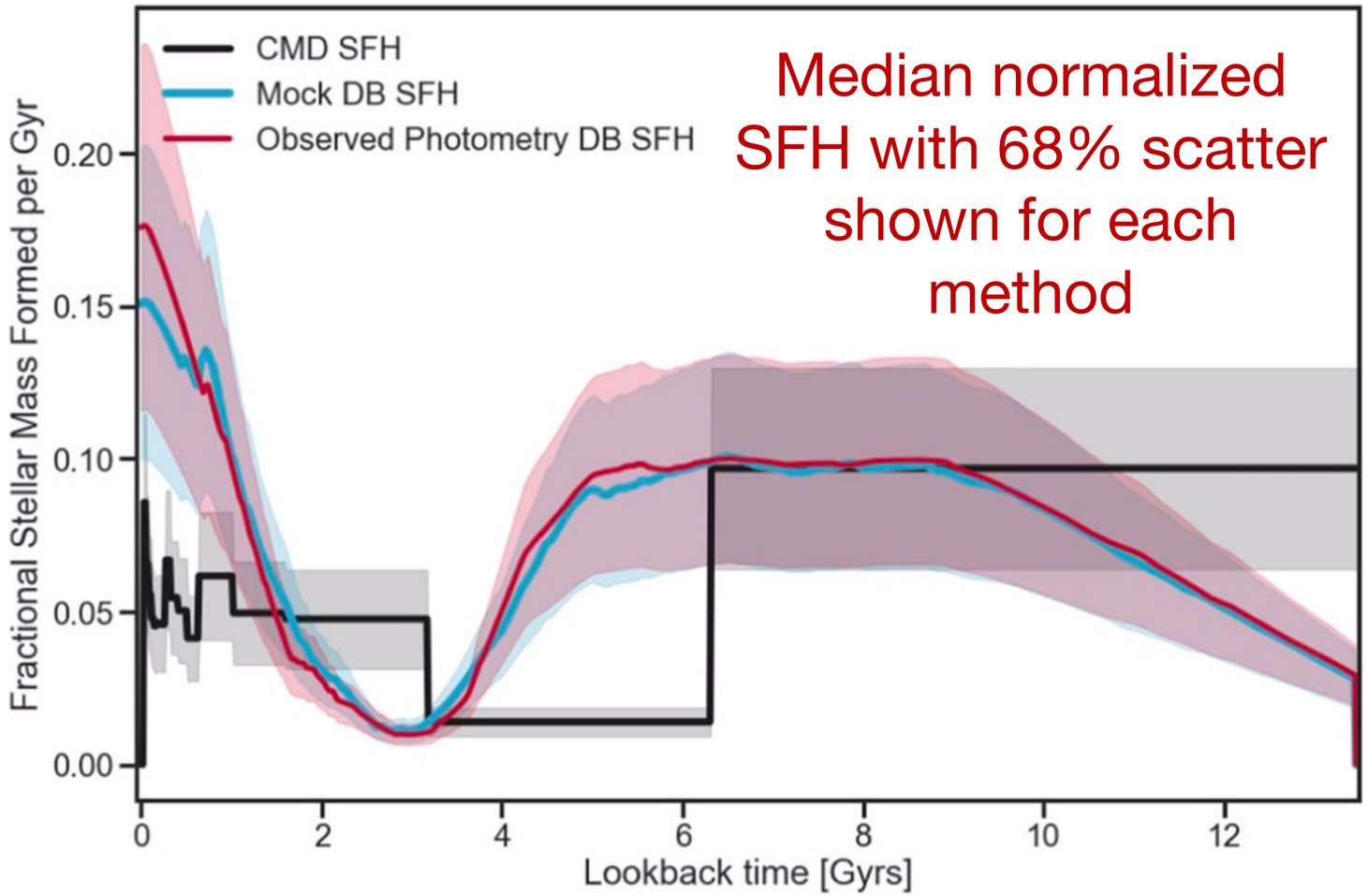
Published 2021 May 24 •




The Astrophysical Journal, Volume 913, Number 1

**Citation** Charlotte Olsen *et al* 2021 *ApJ* **913** 45

# Dense Basis & CMD SFHs for ANGST Dwarf Galaxies at <4 Mpc

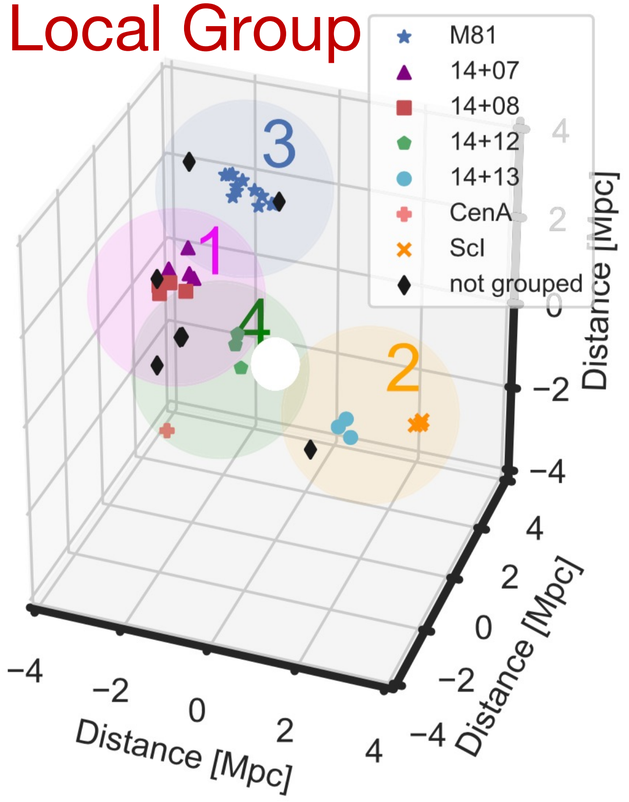



From Olsen+21, ApJ 913, 45

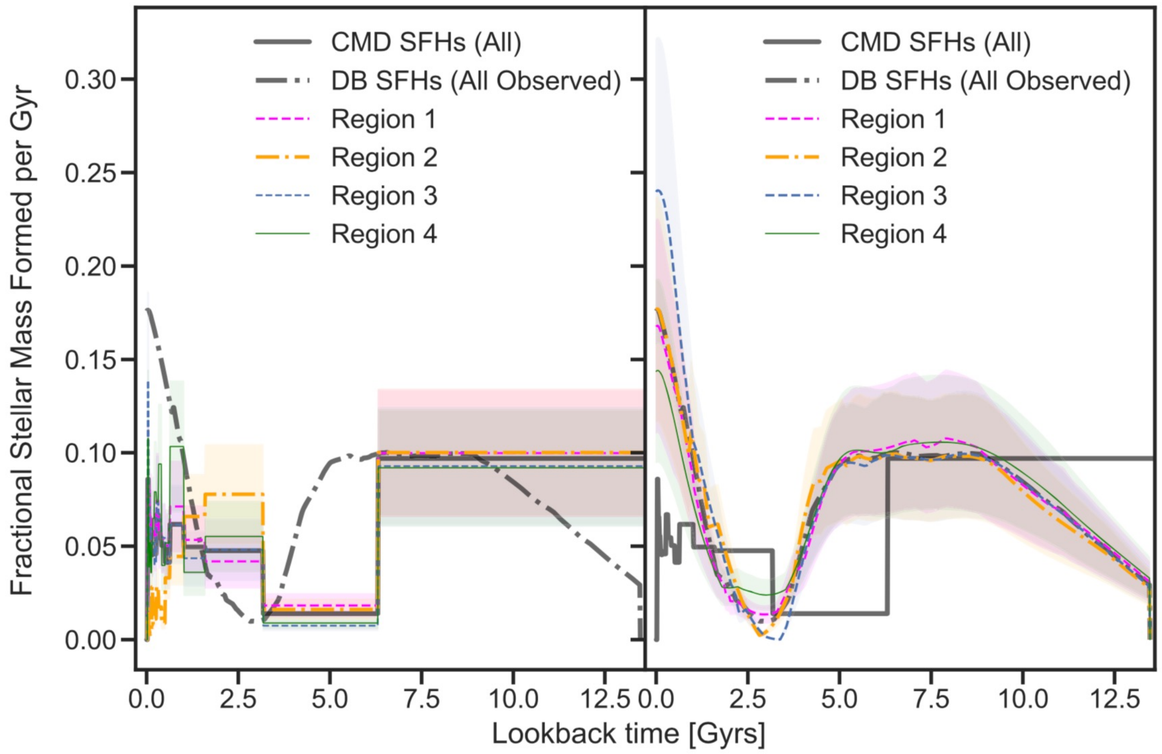
Found a ~1 Gyr systematic offset, but **methods agree that Star Formation Rate declined 4-6 Gyr ago and was rejuvenated 2-3 Gyr ago**. Such **large-scale coordination NOT predicted by galaxy formation models!**

# Dense Basis & CMD SFHs for ANGST Dwarf Galaxies at <4 Mpc

Investigated further by breaking into 4 regions surrounding the Local Group




Median normalized SFH with 68% scatter shown for each method in each region




For both methods, little variation with region:
SFR declined 4-6 Gyr ago and was rejuvenated 2-3 Gyr ago.
Such large-scale coordination NOT predicted by galaxy formation models!

From Olsen+21, ApJ 913, 45

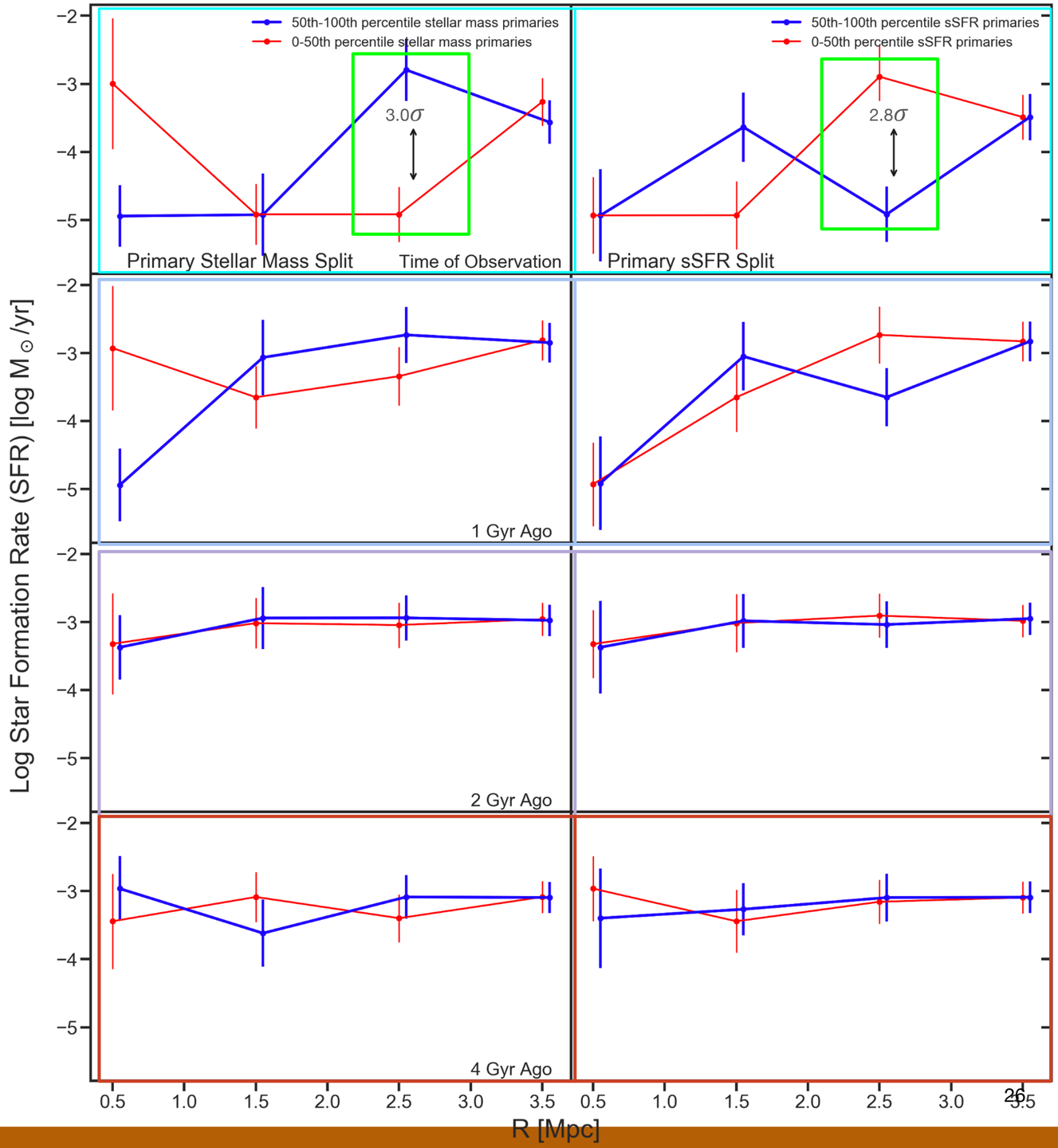
# Search for Conformity Split on Star Formation Rate in Combined LG+LV Sample

When splitting on central stellar mass or sSFR:

found conformity for secondary galaxies 2 to 3 Mpc from their primary at time of observation

**Secondaries separated by 2 to 3 Mpc from high stellar mass and low sSFR primaries are more likely to have high SFR**

From Olsen & Gawiser 23, ApJ 943, 30



# Searching for Conformity Split on Quenched Fraction in Combined LG+LV Sample

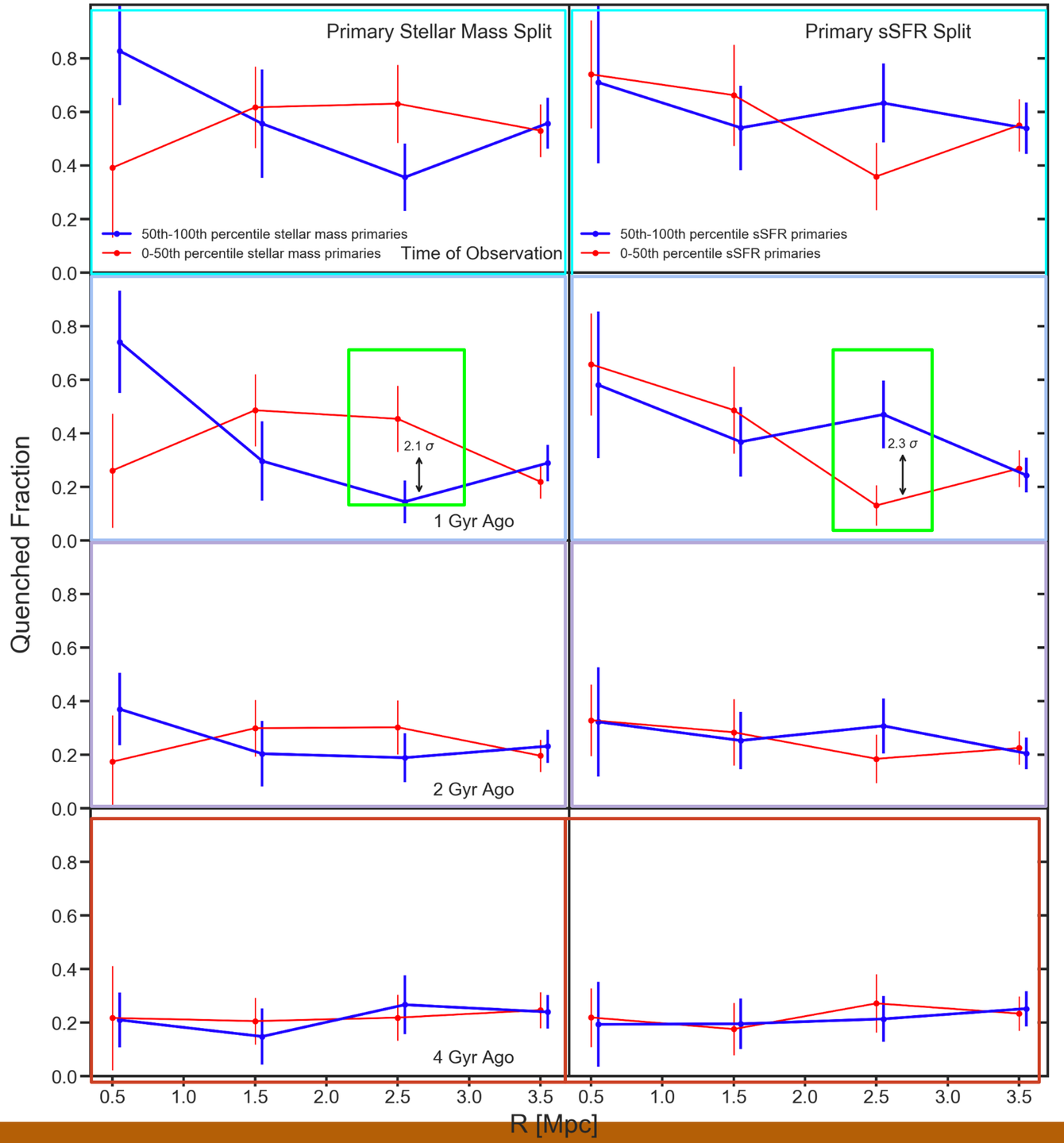
When splitting on central stellar mass or sSFR:

Similar to results for SFR, though weaker signal for 2 to 3 Mpc from their primary

1 Gyr ago

**Secondaries separated by ~2 to 3 Mpc from low stellar mass and high sSFR primaries are more likely to be quenched**

From Olsen & Gawiser 23, ApJ 943, 30



# Is this signal found in the galaxies with synchronized star formation?

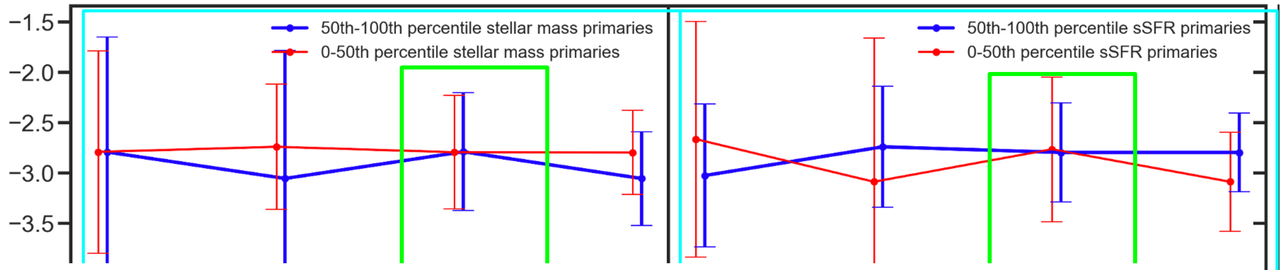
We repeat the same tests with only th

Local Volume.

No conformity in galaxies with synchronized star formation?

Are synchronized star formation and conformity sensitive to different trends?

Conformity signal is sensitive to the geometry of the region we are examining




THE ASTROPHYSICAL JOURNAL

OPEN ACCESS

## Searching for Conformity Across Cosmic Time with Local Group and Local Volume Star Formation Histories

Charlotte Olsen[1] and Eric Gawiser[1]

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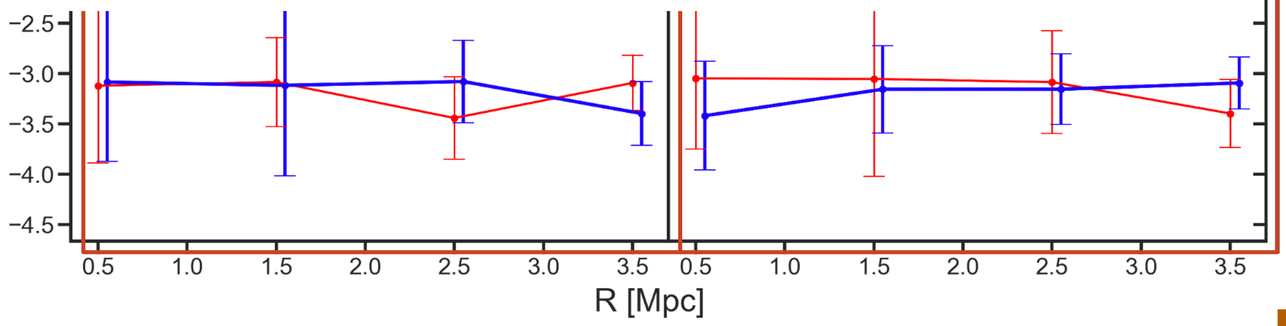
The Astrophysical Journal, Volume 943, Number 1

**Citation** Charlotte Olsen and Eric Gawiser 2023 *ApJ* **943** 30

**DOI** 10.3847/1538-4357/acaa39

Article PDF Article ePub



# ODIN (One-hundred deg$^2$ DECam Imaging in Narrowbands): Goals

1. Find >100,000 Lyman Alpha Emitting (LAE) galaxies at z=4.5,3.1,2.4 to study their clustering and star formation histories
2. Identify >600 galaxy protoclusters as strong overdensities in the angular distribution of LAEs
3. Find hundreds of Lyman Alpha Nebulae (a.k.a. Lya Blobs) via diffuse emission

Built 3 custom narrow-band filters for the Dark Energy Camera (DECam) centered at [419, 501, 673] nm with FWHM of [8,8,10] nm

Just need 3 months of observing time on DECam…

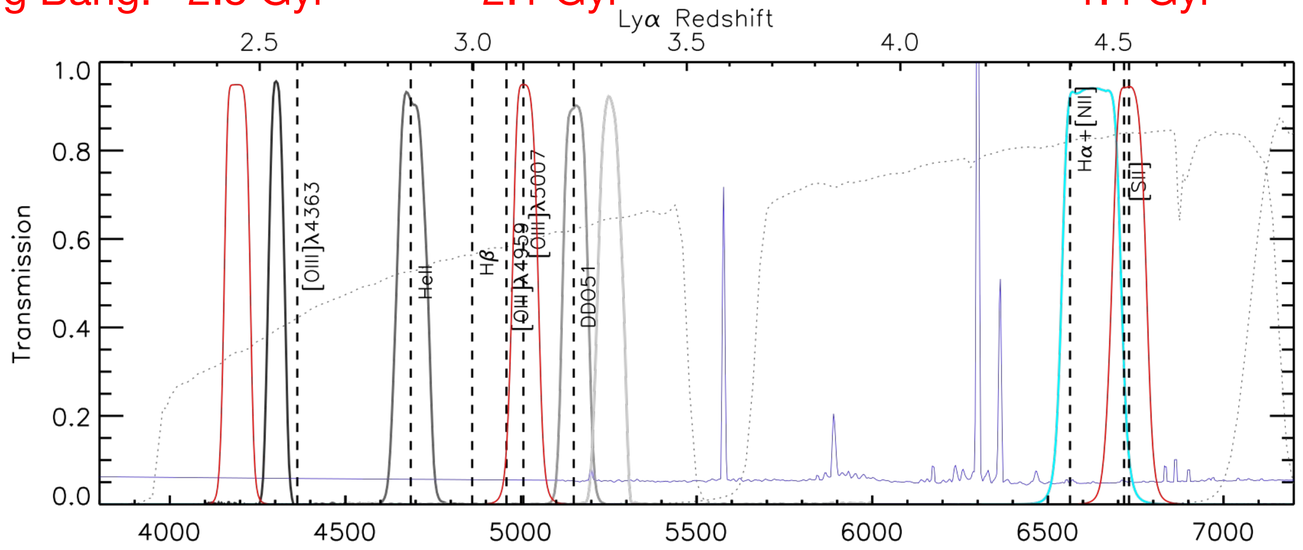
# ODIN

Awarded a NOIRLab Survey for 2021-2024

PI Kyoung-Soo Lee (Purdue)

Council includes Co-PI Eric Gawiser, Changbom Park (KIAS) & Yujin Yang (KASI)

Time since Big Bang: 2.8 Gyr 2.1 Gyr 1.4 Gyr




existing DECam Narrowband filter

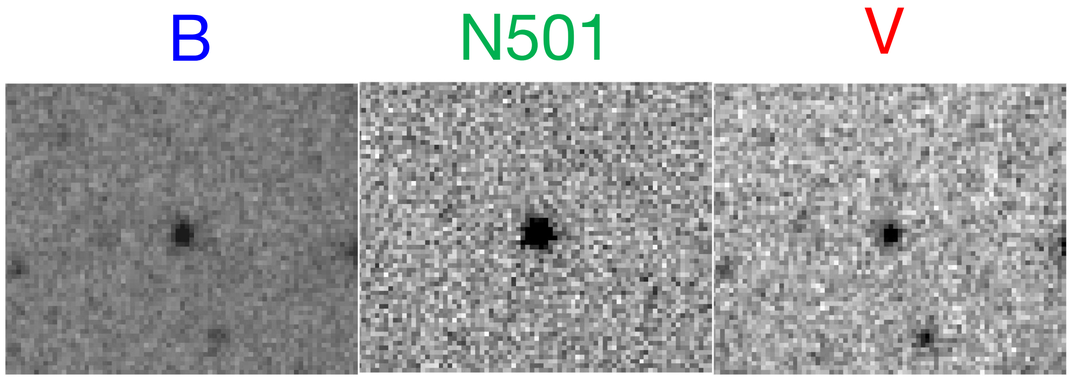
new DECam Narrowband filters

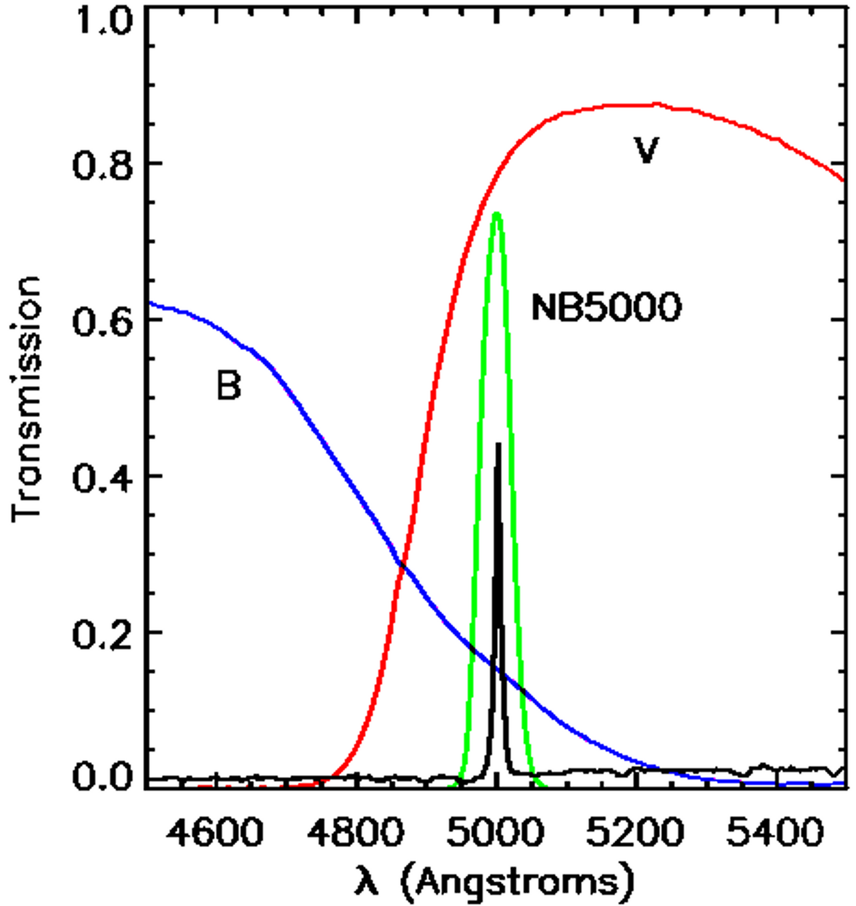
Subaru HSC Narrowband filters

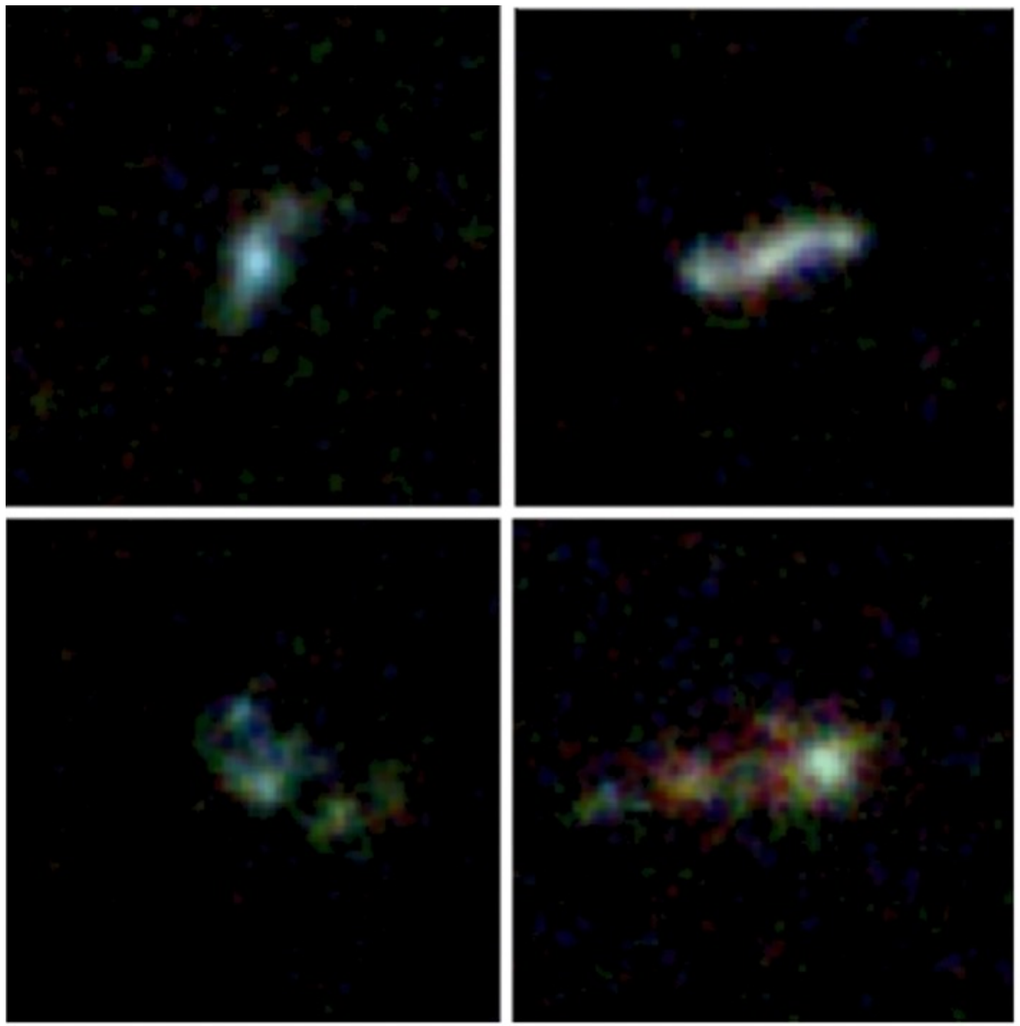
atmospheric emission

--------- emission lines

# Lyman Alpha Emitter (LAE) at z=3.1



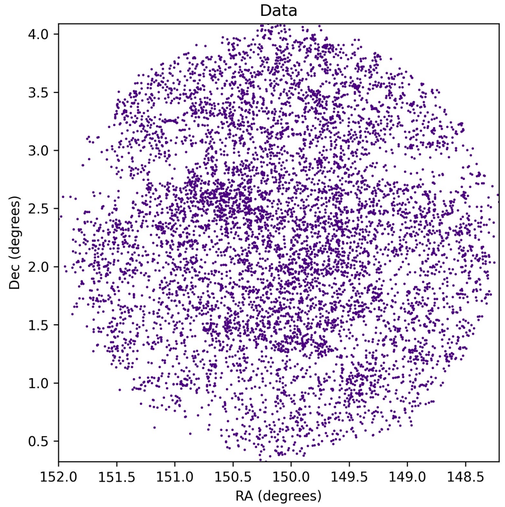



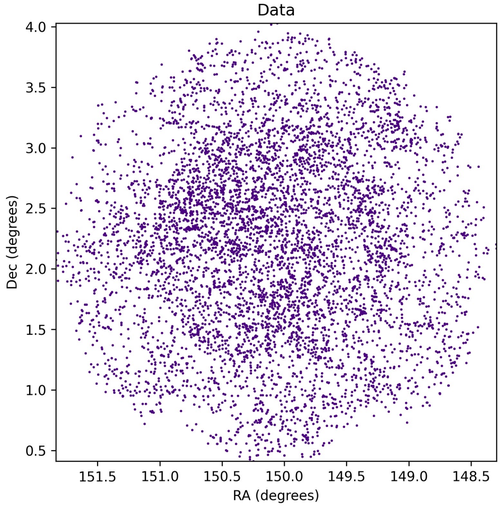
Hubble Space Telescope resolves ~half of LAEs; Half-light radii <~2 kpc

# Sky distribution of Lyman Alpha Emitting (LAE) galaxies

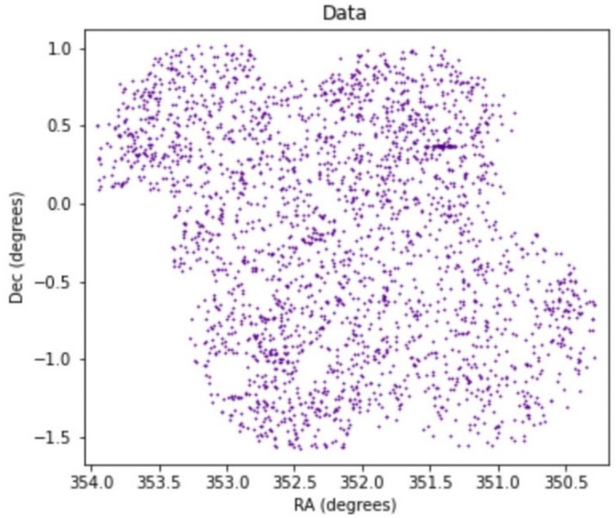
z=3.1 LAE candidates selected by UG student Rameen Farooq



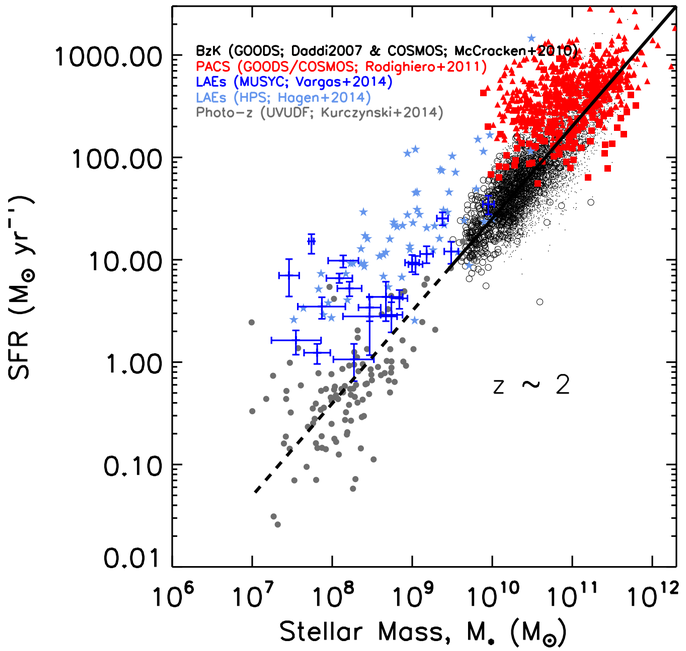

z=4.5 LAE candidates selected by REU student Shreya Karthikeyan

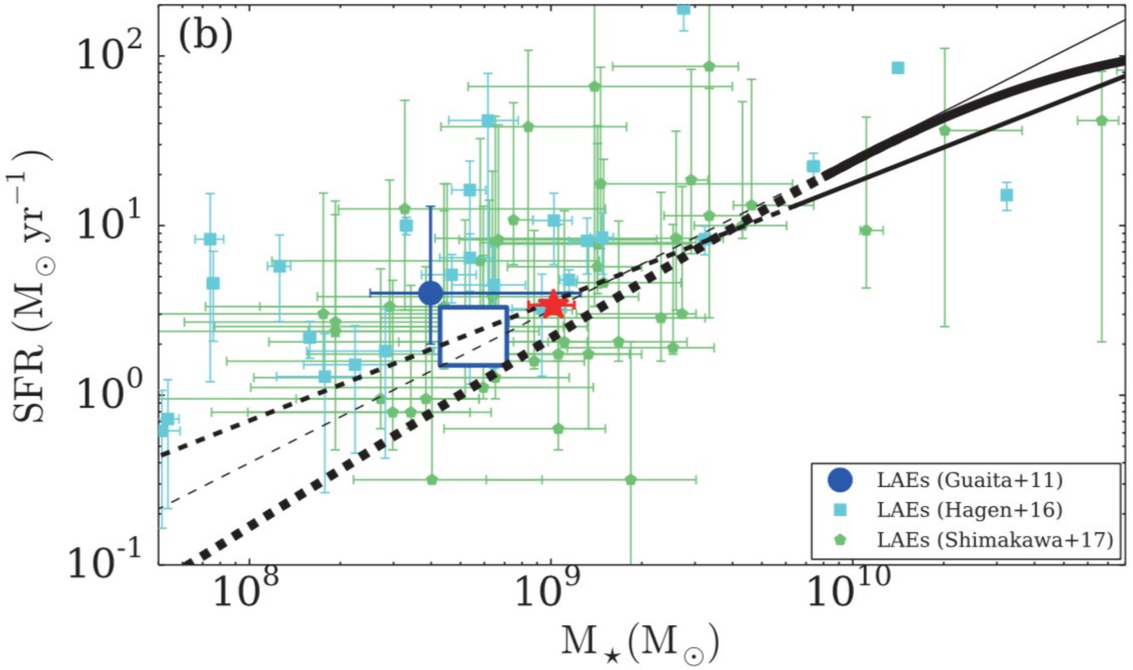



z=2.4 LAE candidates selected by grad student Nicole Firestone



# Where do z=2 Lyman Alpha Emitters (LAEs) lie on the SFR-M* Diagram?




LAEs lie above the correlation; they are undergoing starbursts!
(Vargas+14, ApJ 783, 26; Hagen+14 ApJ 786, 59;
Santos+20 MNRAS 493, 161)

LAEs lie on the correlation; LAEs follow an SMC dust law, even though the correlation was determined assuming Calzetti dust law for other galaxies (Kasakabe+18, PASJ 70, 4)

ODIN will resolve this via Dense Basis SED Fitting using Gaussian Process SFH reconstruction with a flexible dust law for both LAEs and continuum-selected galaxies in the CANDELS fields

# Conclusions

- Careful analysis of galaxy Spectral Energy Distributions allows us to reconstruct their star formation histories, which are a powerful tool for probing galaxy evolution.
- Looking at correlations between Local Volume dwarf galaxies, we found synchronized star formation features at ~3 and ~6 Gyr lookback time.
- Using the SFHs of Local Group and Local Volume galaxies, we found signs of conformity that were independent of synchronized star formation.
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