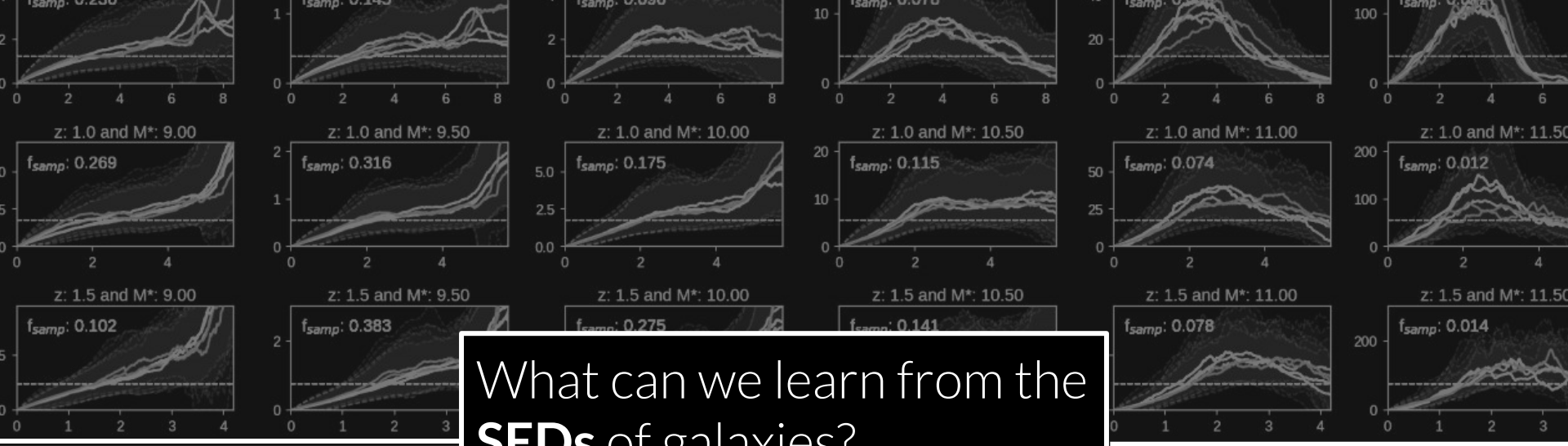


What can we learn from the **SEDs** of galaxies?

(*SED: Spectral Energy Distribution)

Kartheik **Iyer**

Dunlap Postdoctoral Fellow

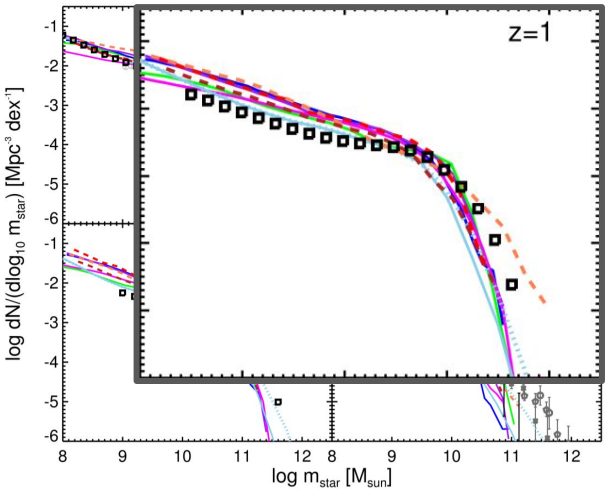
.Astronomy 11, 22nd October 2019

UNIVERSITY OF TORONTO

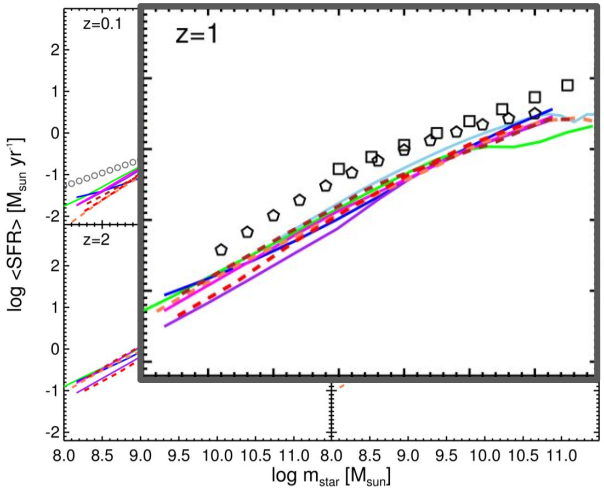
DUNLAP INSTITUTE *for* **ASTRONOMY & ASTROPHYSICS**

Distributions of galaxy properties* enable us to formulate and test theories of how galaxies evolve.

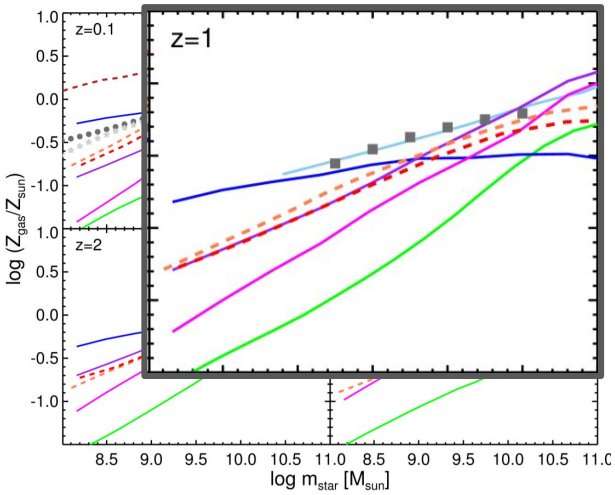
Mass Functions



SFR-M$_*$ correlation



Z$_{gas}$-M$_*$ correlation



Points: **observations**
Curves: **theoretical models**

Somerville & Dave' 15 (ArXiv:1412.2712)

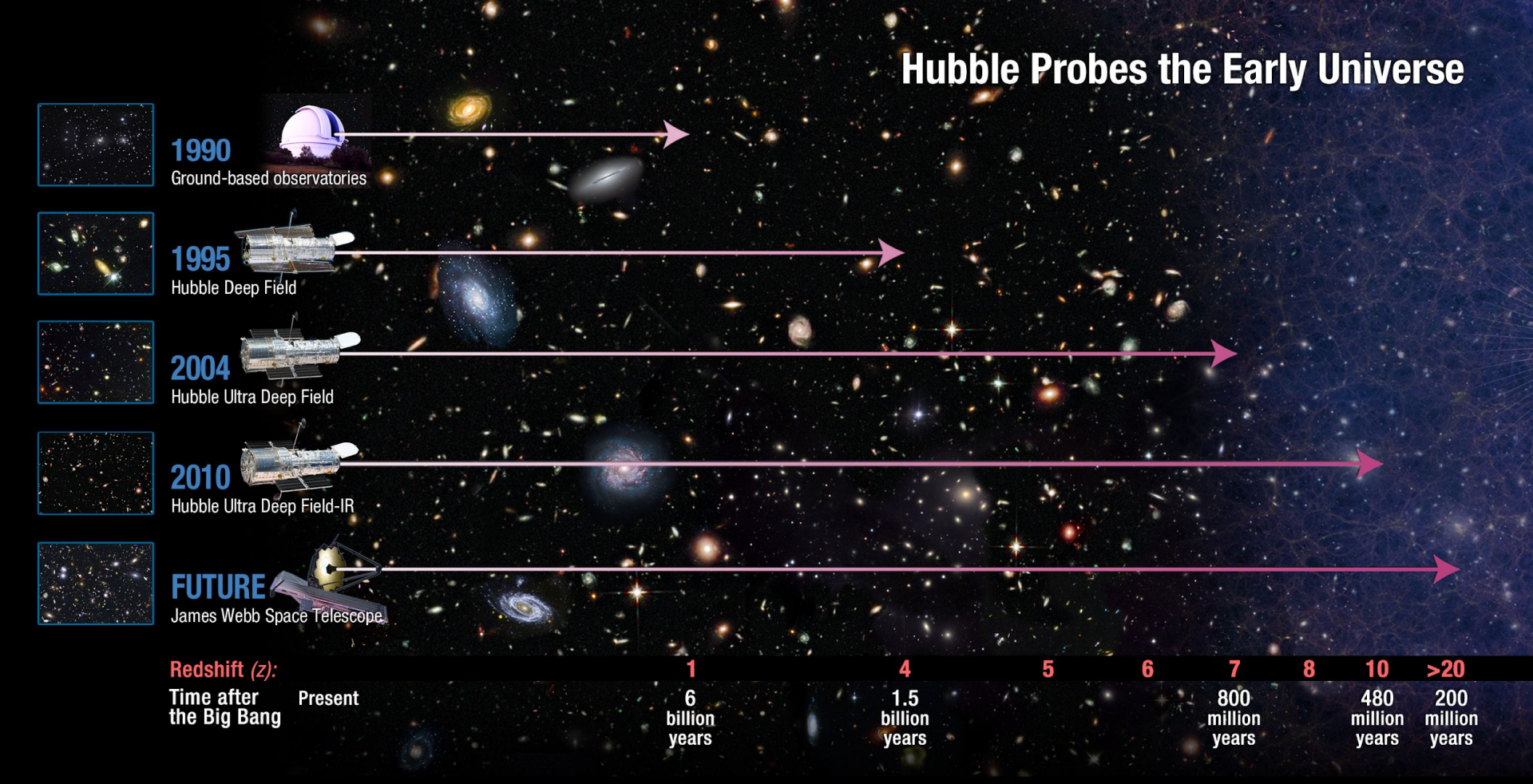
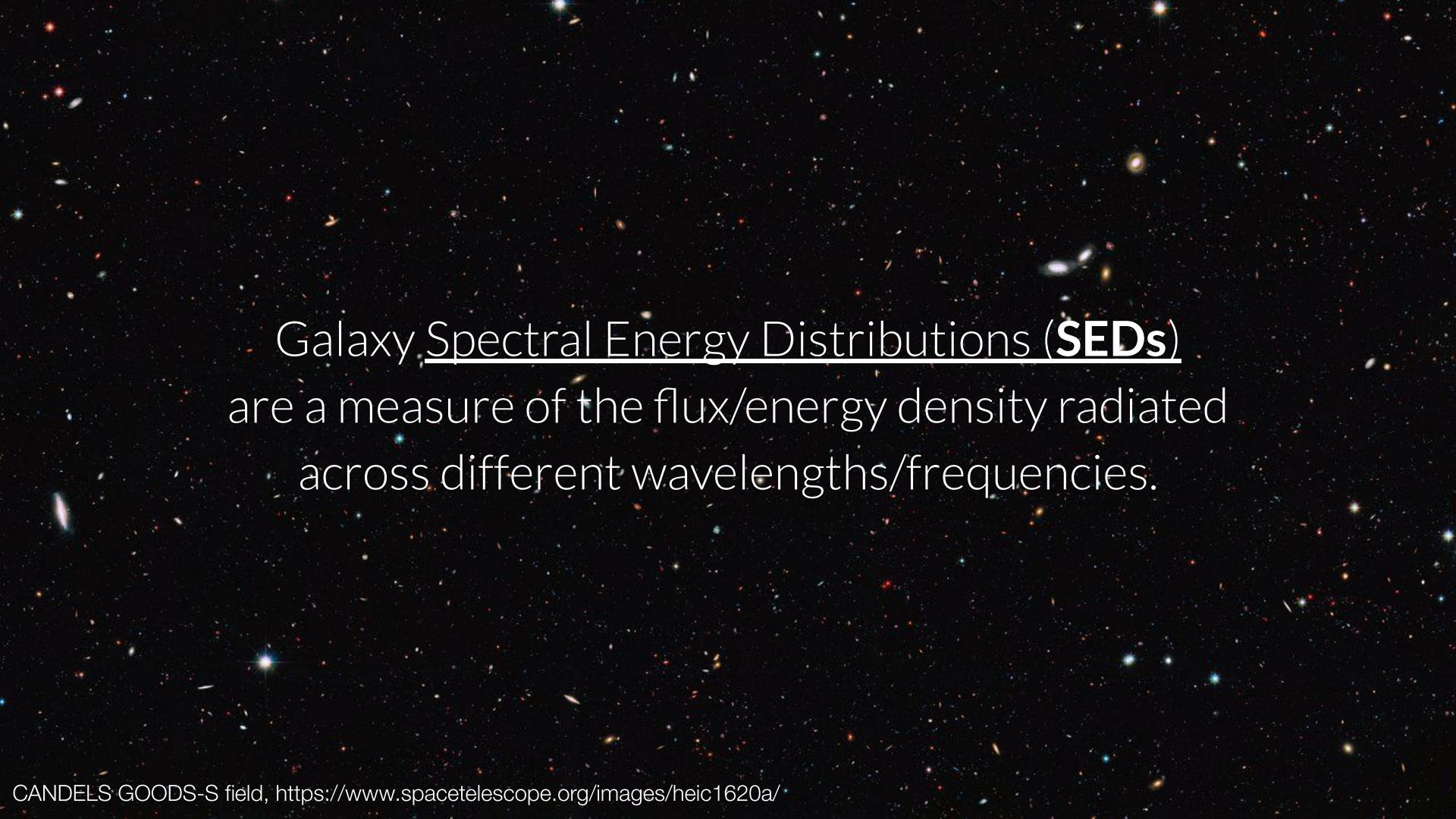
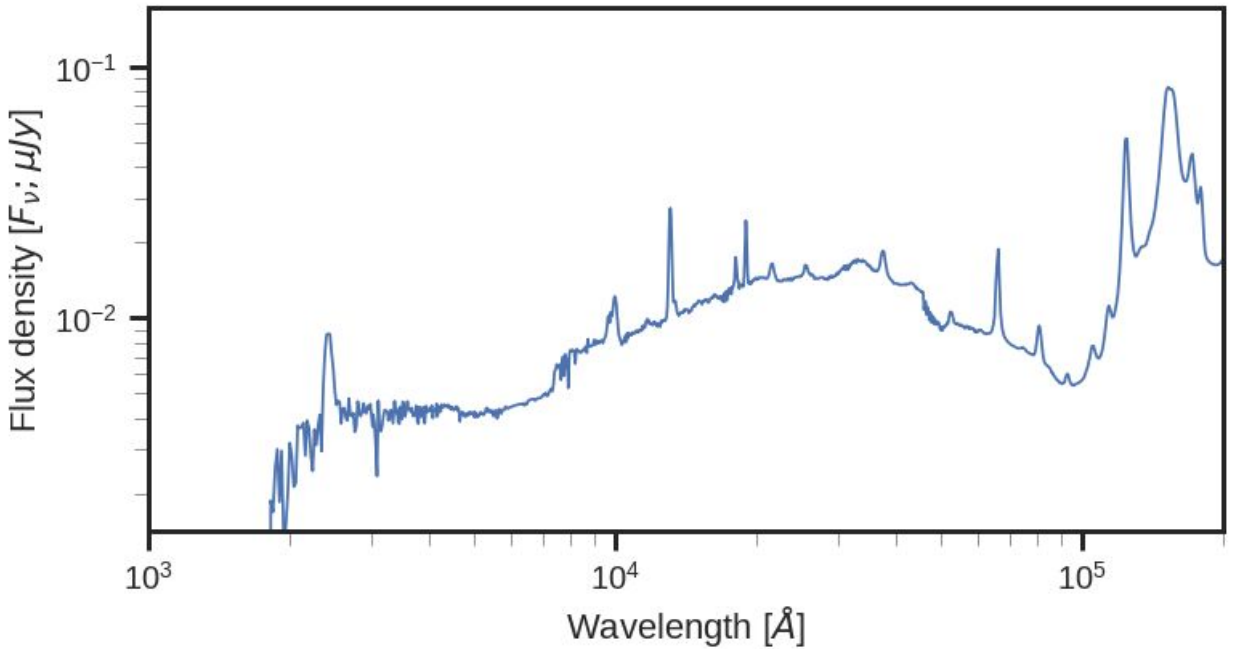


Illustration: NASA, ESA, and A. Feild (STScI); Science: NASA, ESA, G. Illingworth (University of California, Santa Cruz), R. Bouwens (University of California, Santa Cruz, and Leiden University), and the HUDF09 Team

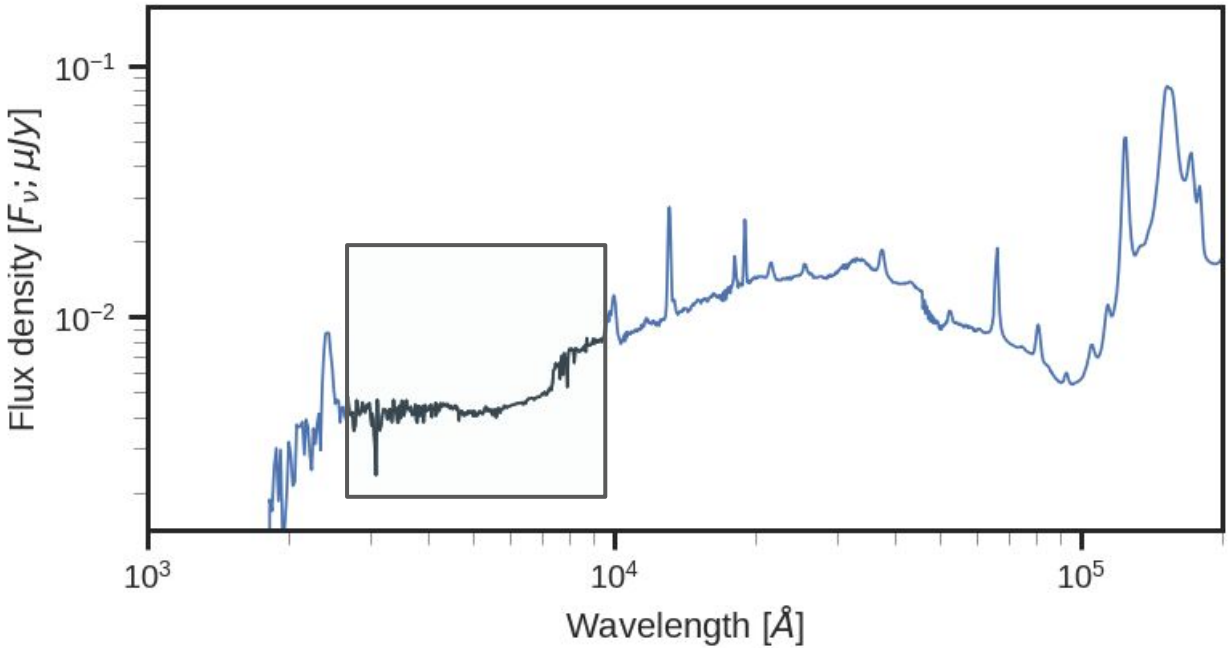


CANDELS GOODS-S field, https://www.spacetelescope.org/images/heic1620a/


10^{-1}
10^{-2}
Flux density [F_ν; μJy]
10^3
10^4
10^5
Wavelength [Å]

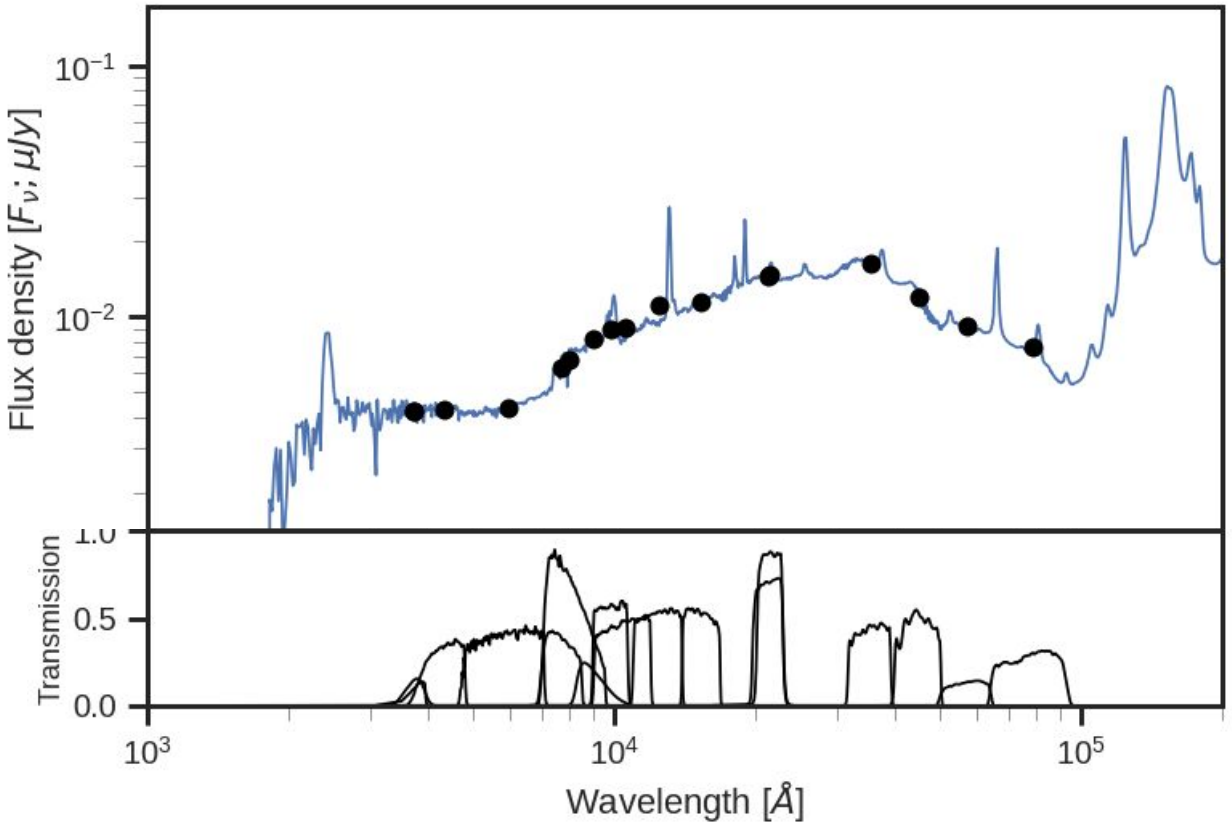
SEDs can be spectroscopic

(more information, but smaller datasets)



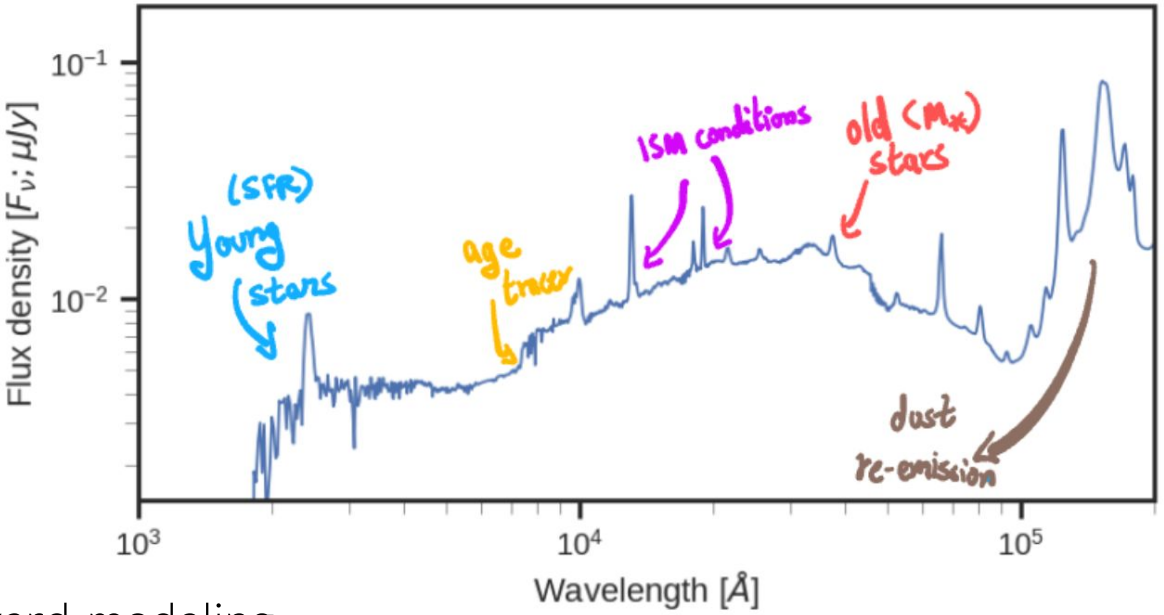
SEDs can be photometric

(less information, but larger datasets)



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 ISM gas)
- Dust properties
- AGN properties

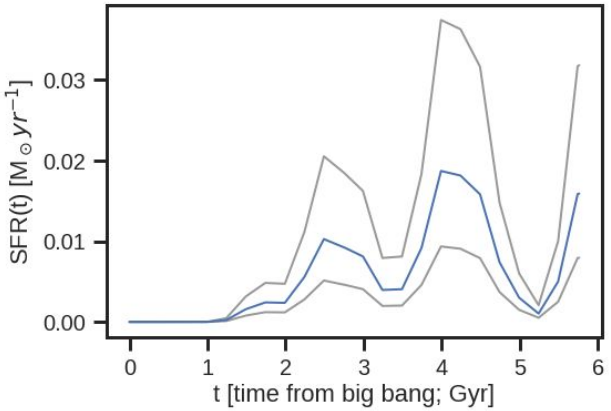


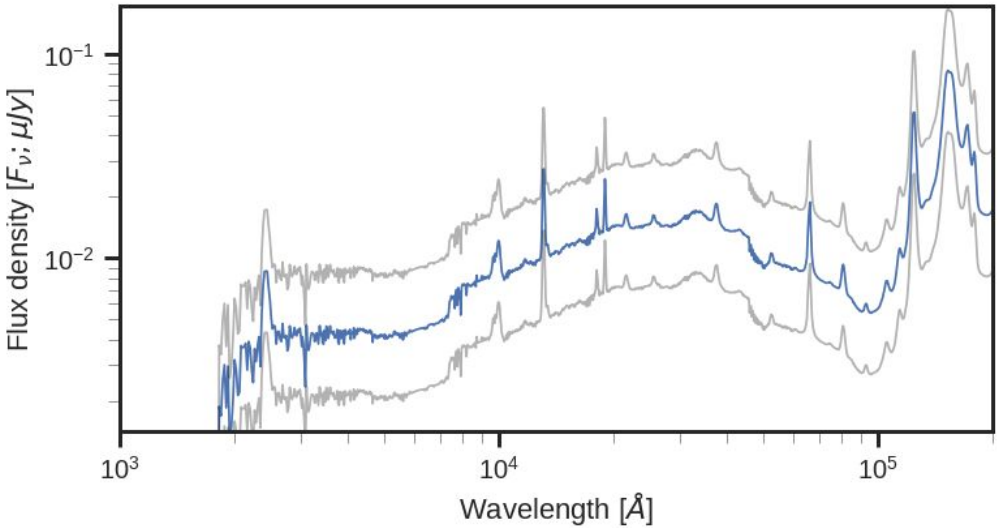
We infer these properties by forward-modeling SEDs using stellar population synthesis models (stellar tracks and isochrones)

Ingredients in SED modeling

- Stellar population synthesis models (stellar tracks and isochrones)
- IMF (initial mass function)
- **SFH (star formation history)**
- Dust attenuation
- Metallicity
- Nebular emission

and many more...





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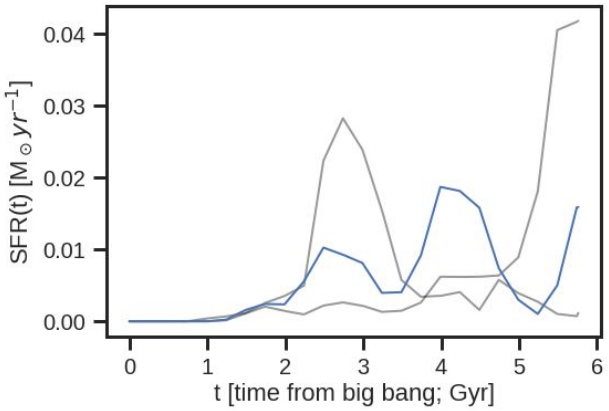

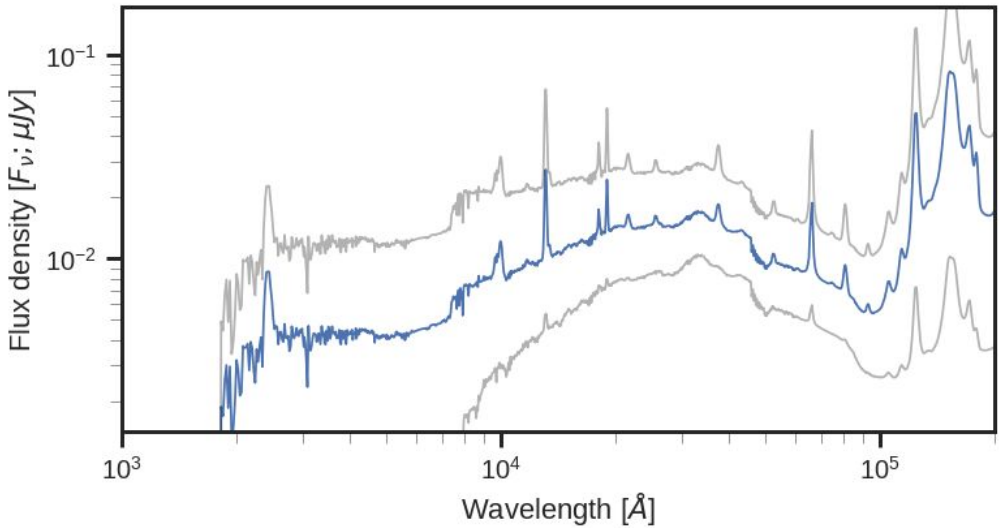

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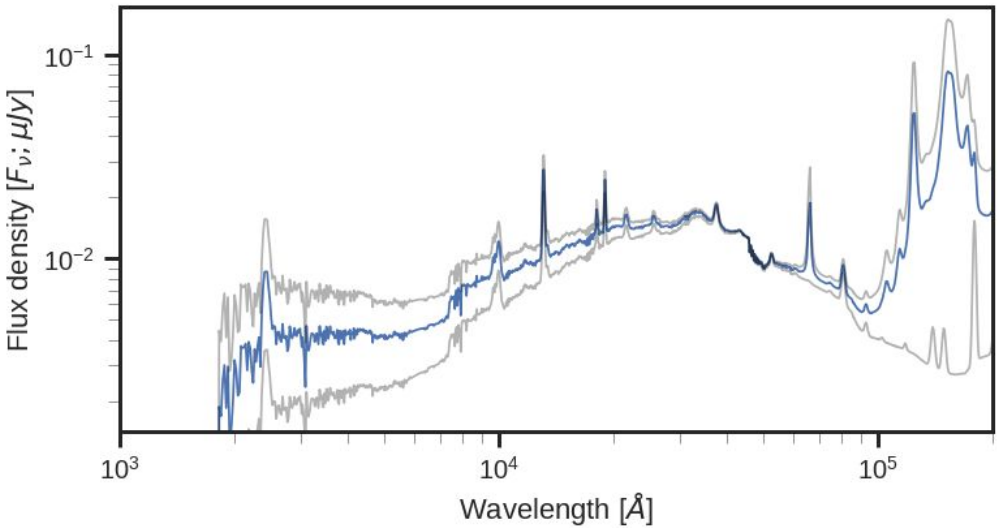

Principled SED modeling
(Iyer & Gawiser '17, Iyer+19)

Be as explicit as possible about modeling assumptions and systematics.

Priors are assumptions too! Flat priors are not necessarily uninformative.

Encode maximum information in the minimum number of parameters.

Number of parameters can be determined from the data being fit.

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Eazy (Brammer et al. 2008)
GalMC (Acquaviva et al. 2011)
LePhare (Arnouts et al. 2011)
SED3FIT (Berta et al. 2013)
FITSED (Salmon et al. 2015)
(Pacifici et al. 2012,16)
AGNfitter (Rivera et al. 16)
Dense Basis (Iyer et al. 2017,19)
Beagle (Chevallard et al. 2017)
Prospector (Leja et al. 2017)
Bagpipes (Carnall et al. 2018)
Cigale (Boquien et al. 2019)
and more (see http://sedfitting.org/Fitting.html)

The basics of **SED fitting**

For a given SED***obs***:

- Model SEDs using preferred method (be clear about your assumptions/priors)

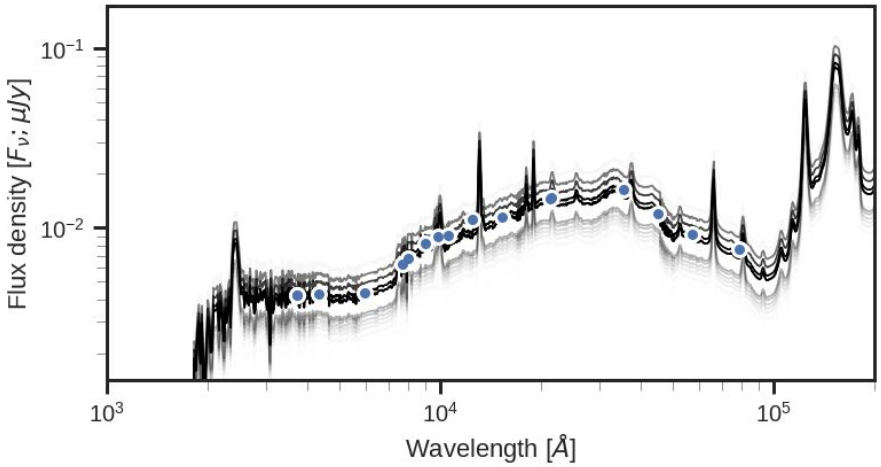
such that you have SED***model***(M_*, SFR, ...)

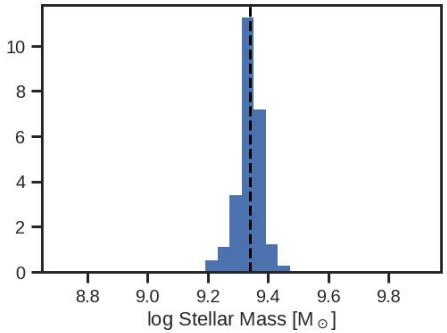
- Write down a likelihood function that takes i account any errors/covariances in SED***obs***

- Using an optimization routine (grid search, brute-force, MCMC, nested sampling etc.), find the posterior: P(model|SED***obs***)

- Marginalize over nuisance parameters to obtain credible intervals for the parameters of interest,

eg. M_*, SFR, Z.





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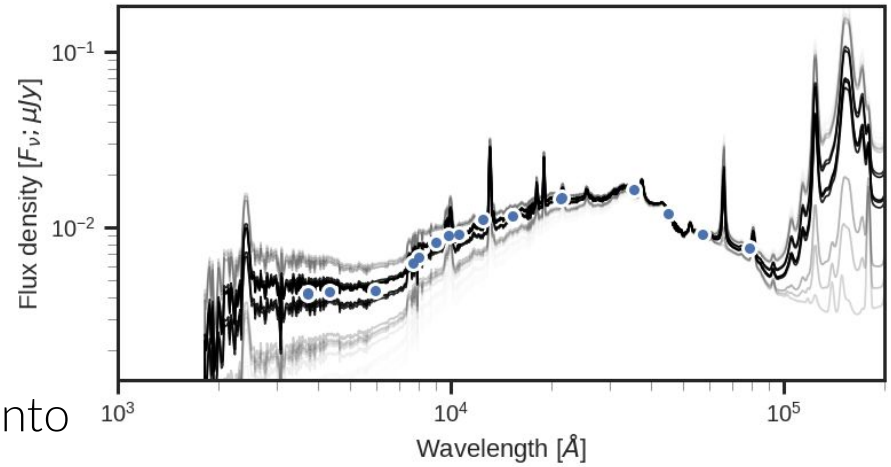

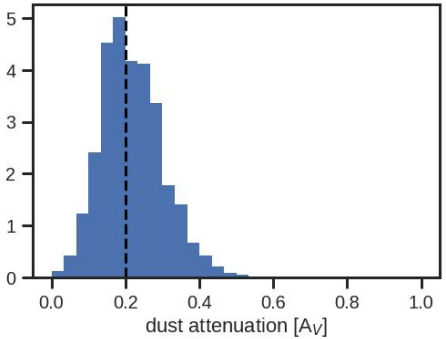

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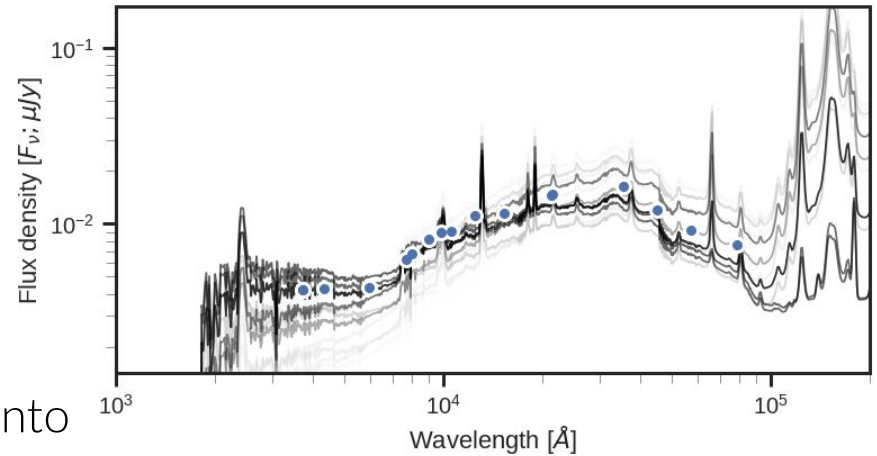
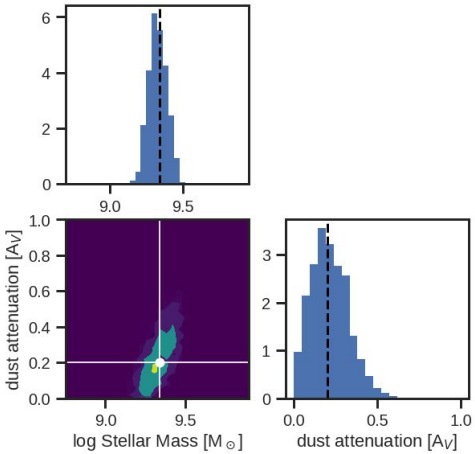
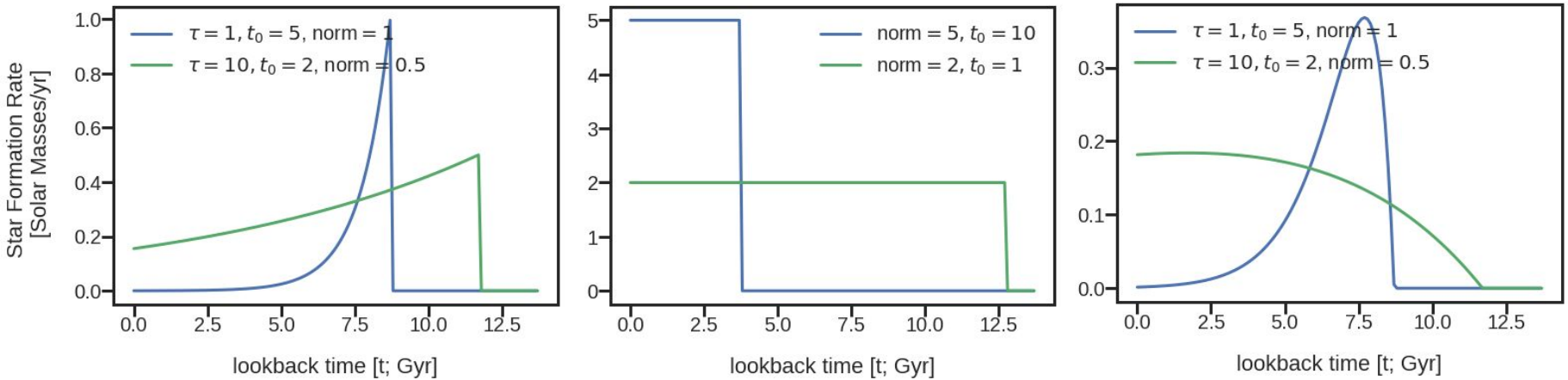




A harder inference problem:
the ***star formation histories*** of galaxies

Simple parametric forms.

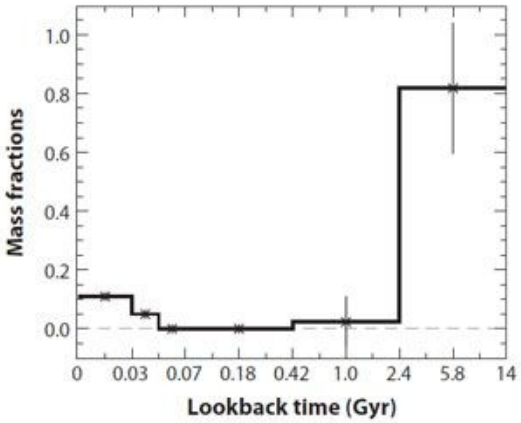
e.g. exponentially declining, constant, lin-exp, lognormal SFHs

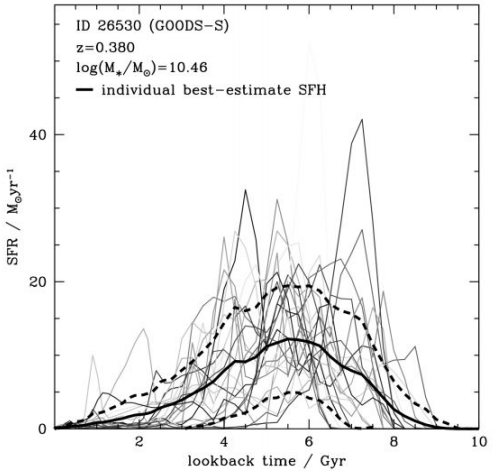


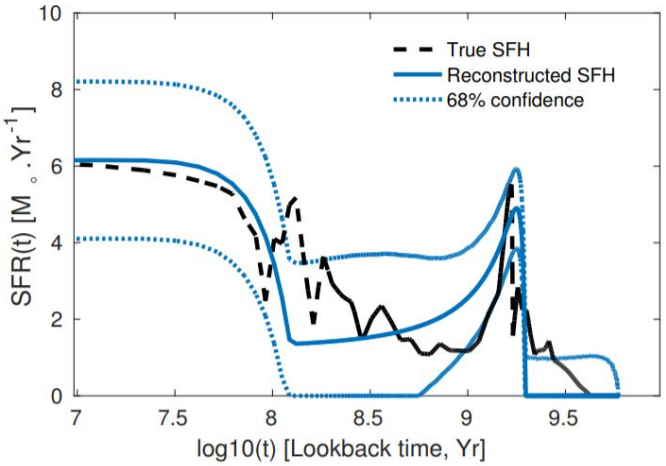
SFH: Star Formation History

Nonparametric SFHs

e.g. SFHs binned in lookback time, SFHs from simulations, multiple parametric forms...







Figures from Tojiero+09 | (ArXiv:0904.1001); Pacifici+16 | (ArXiv:1609.03572); Iyer & Gawiser (2017) | (ArXiv: 1702.04371)

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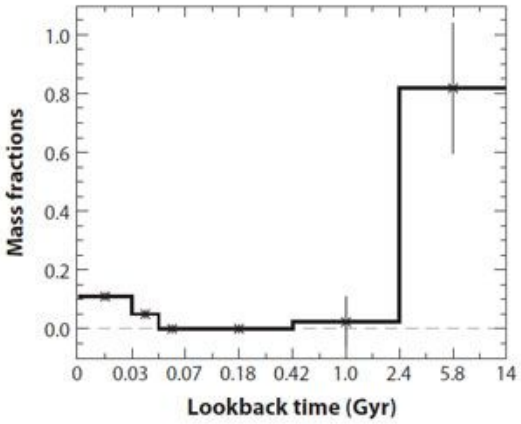

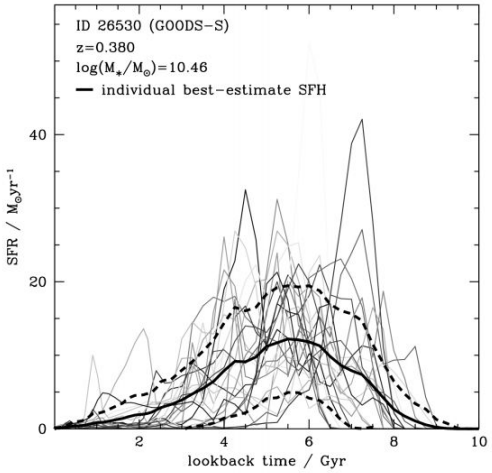

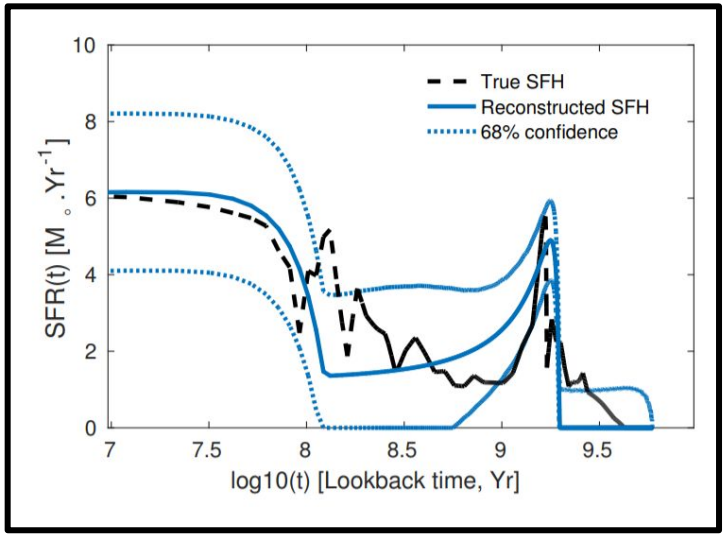

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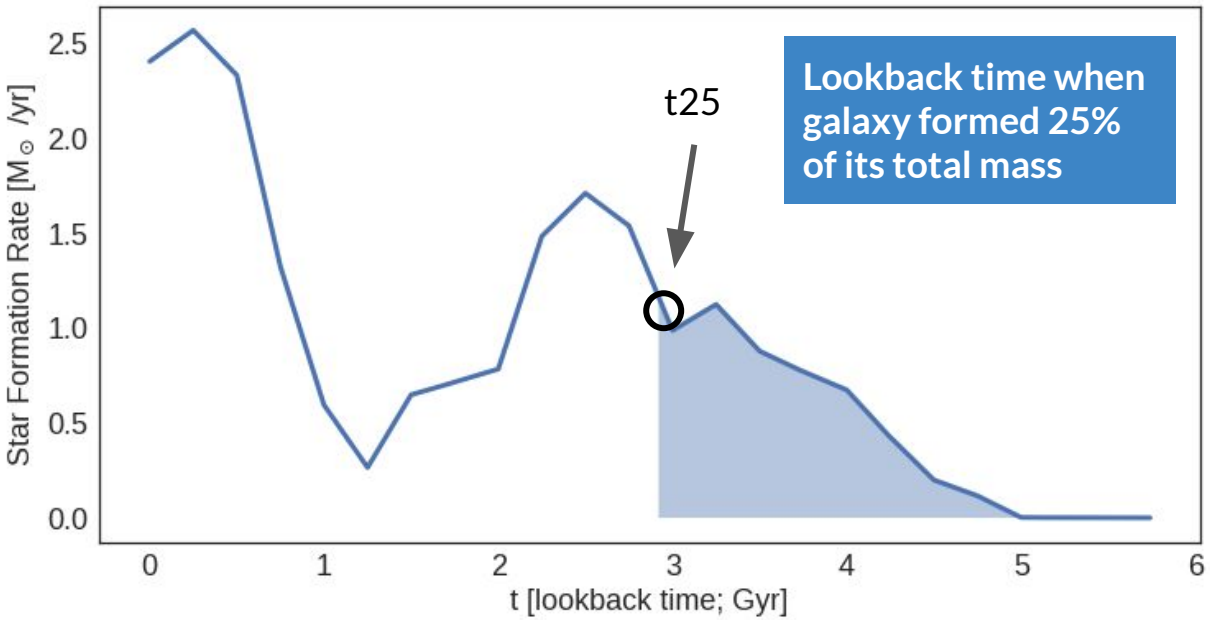
Dense Basis v2.0:
A flexible parameterization in (t_x)

Describe SFH with a tuple:

(M_*, SFR, [t_x])



SFH from Somerville+15a semi-analytic model

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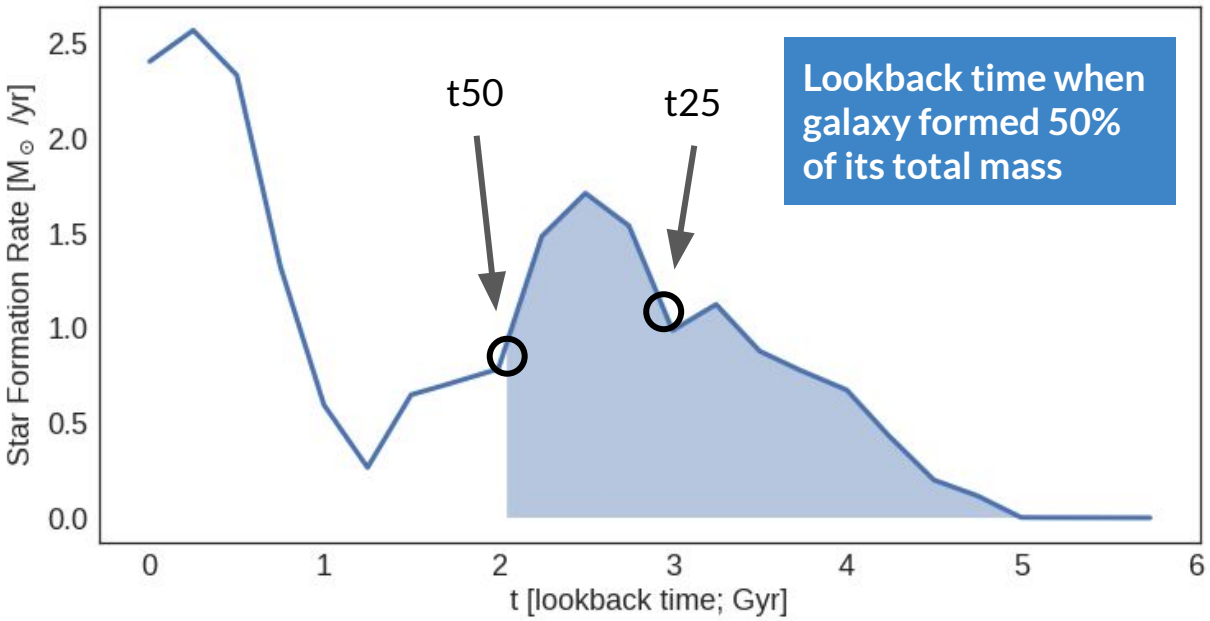

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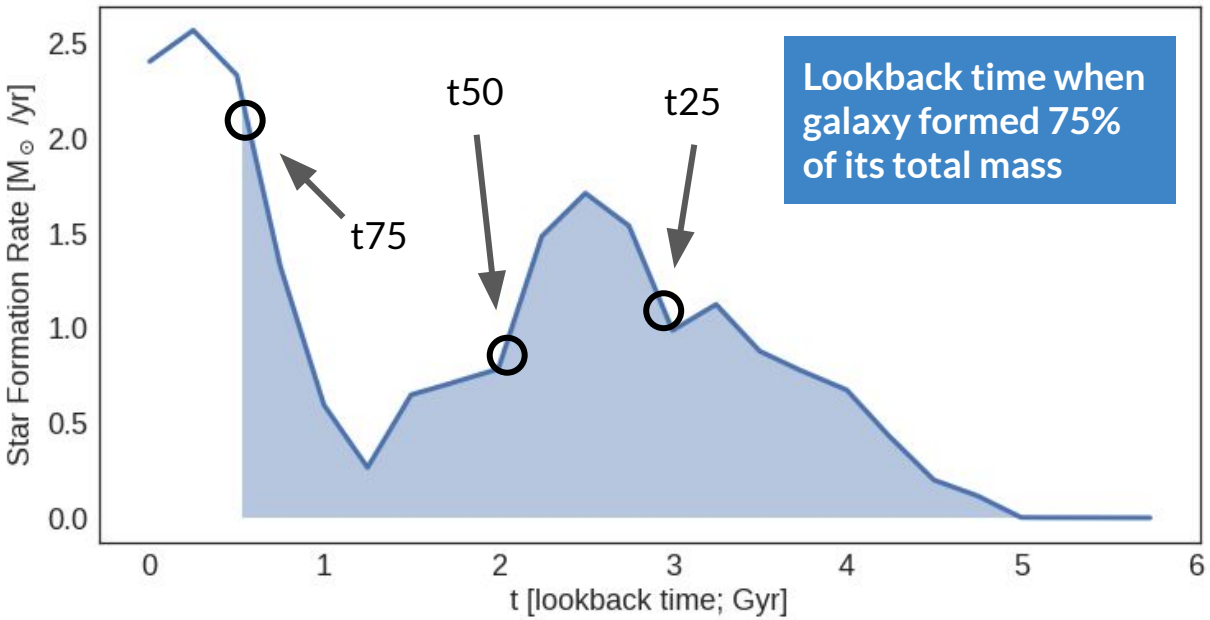

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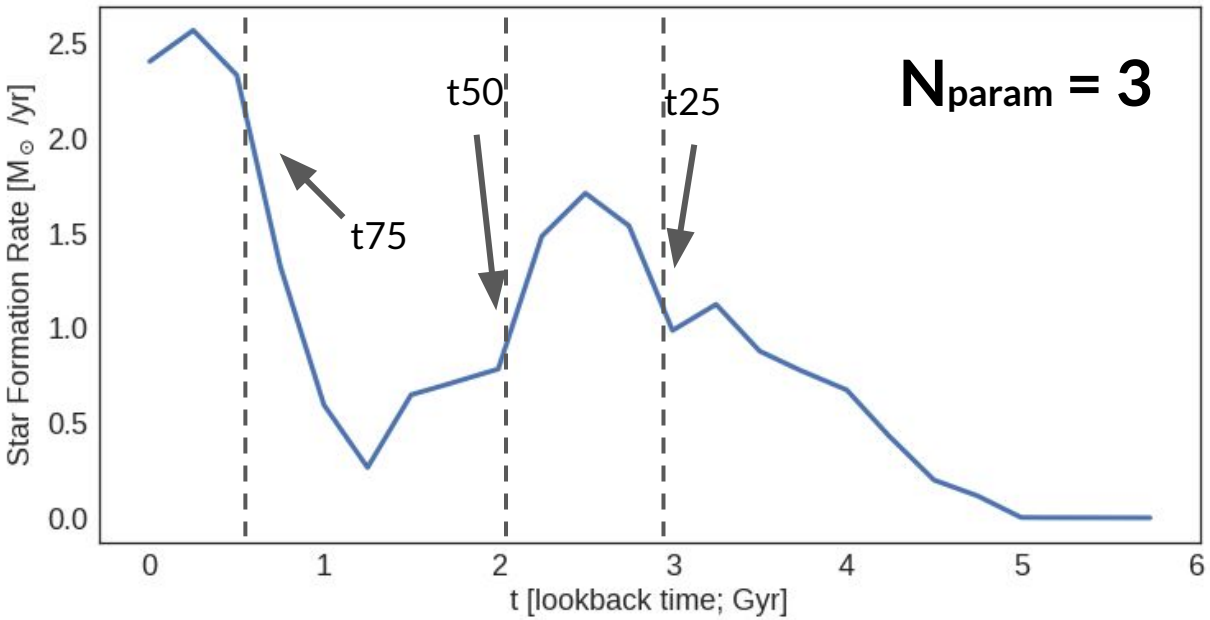

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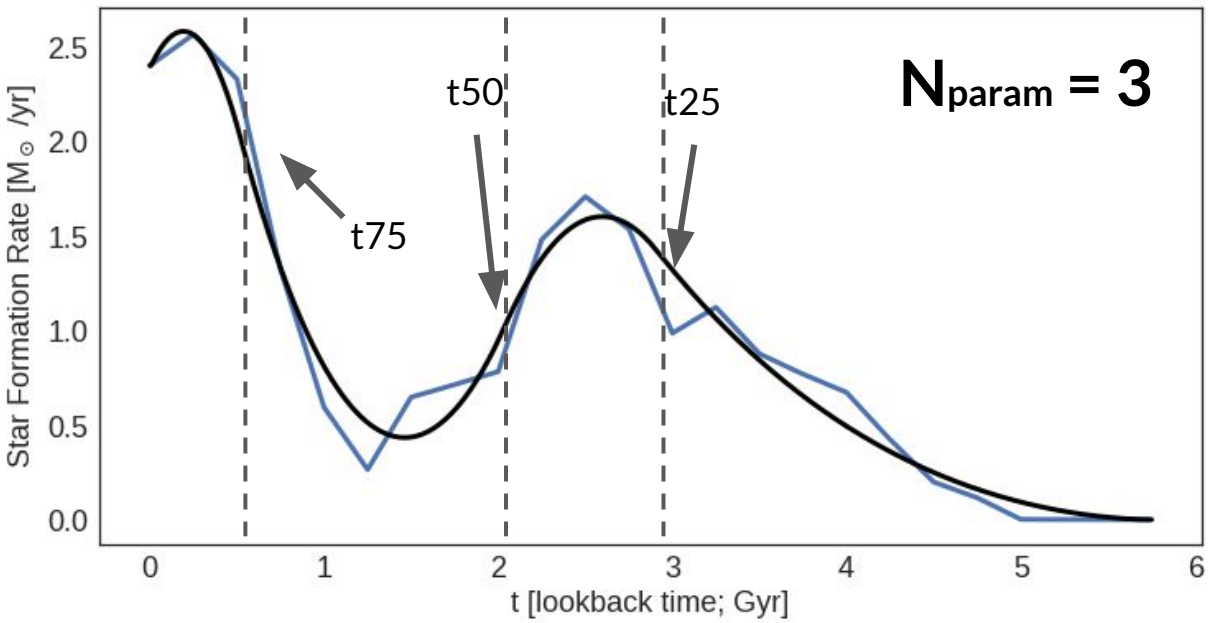

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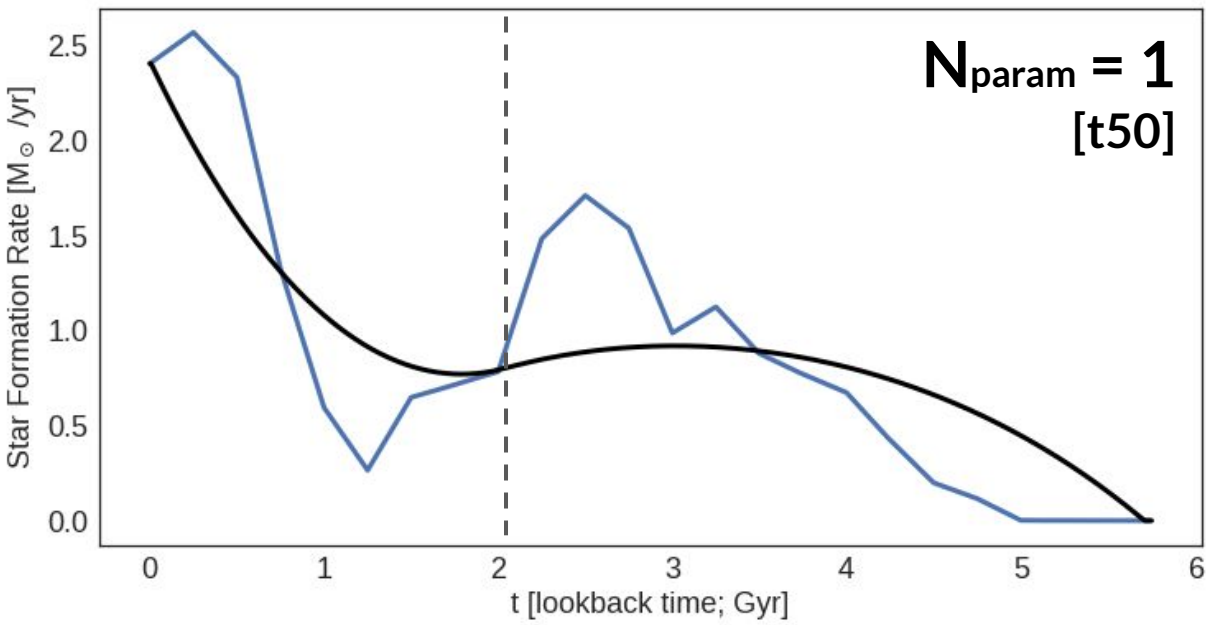

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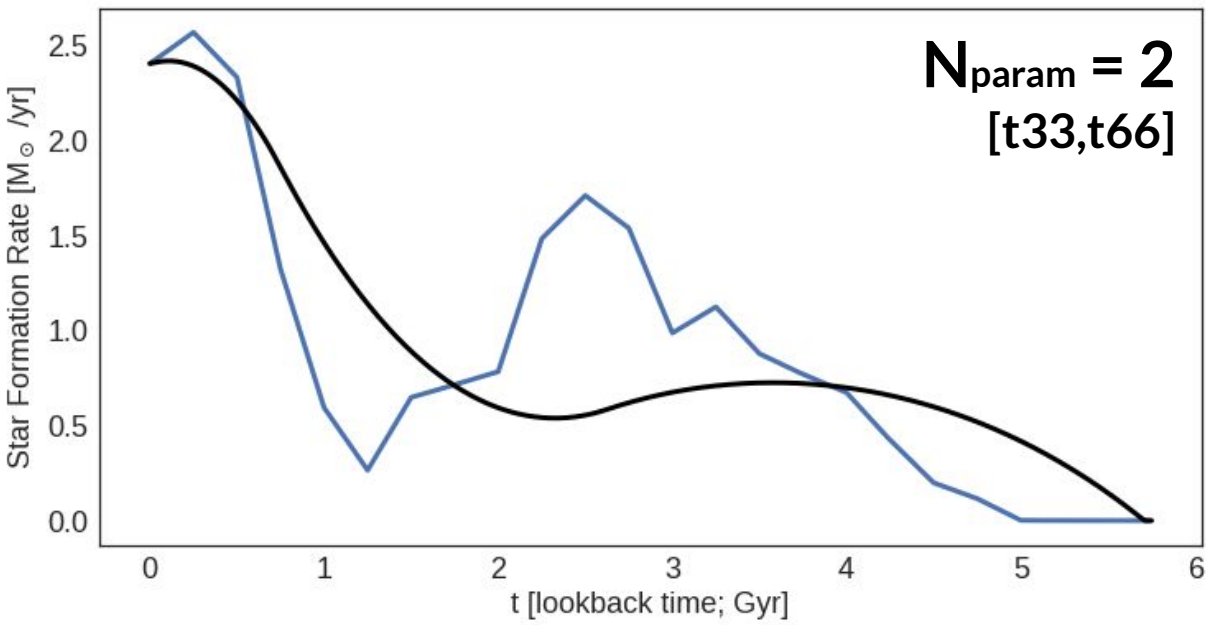

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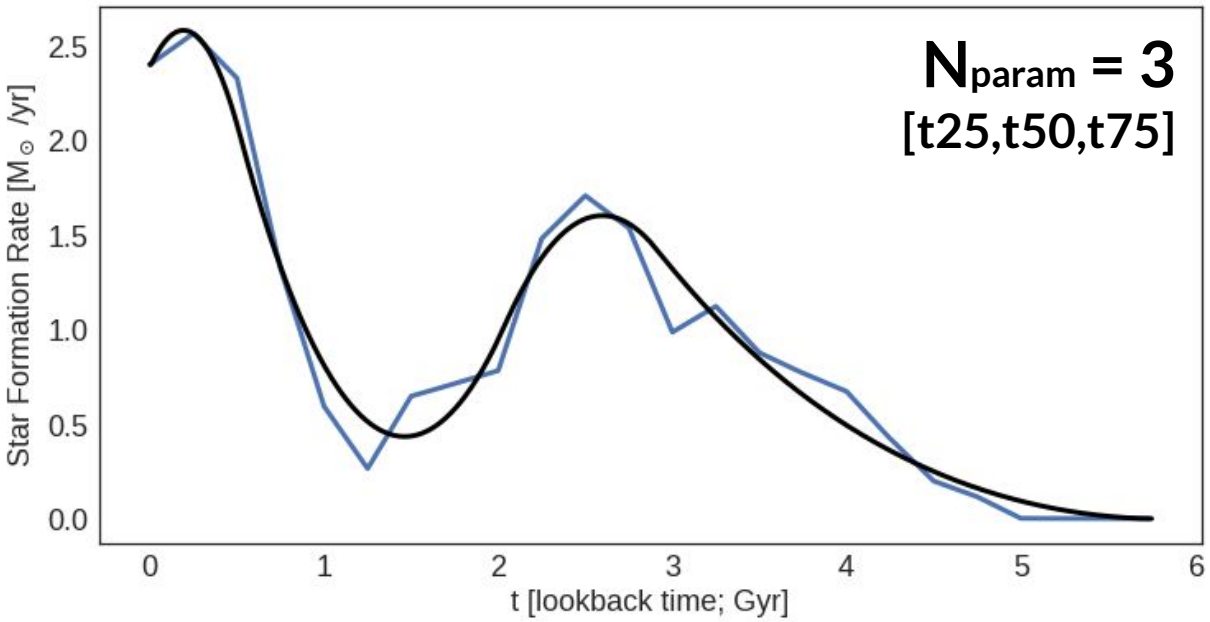

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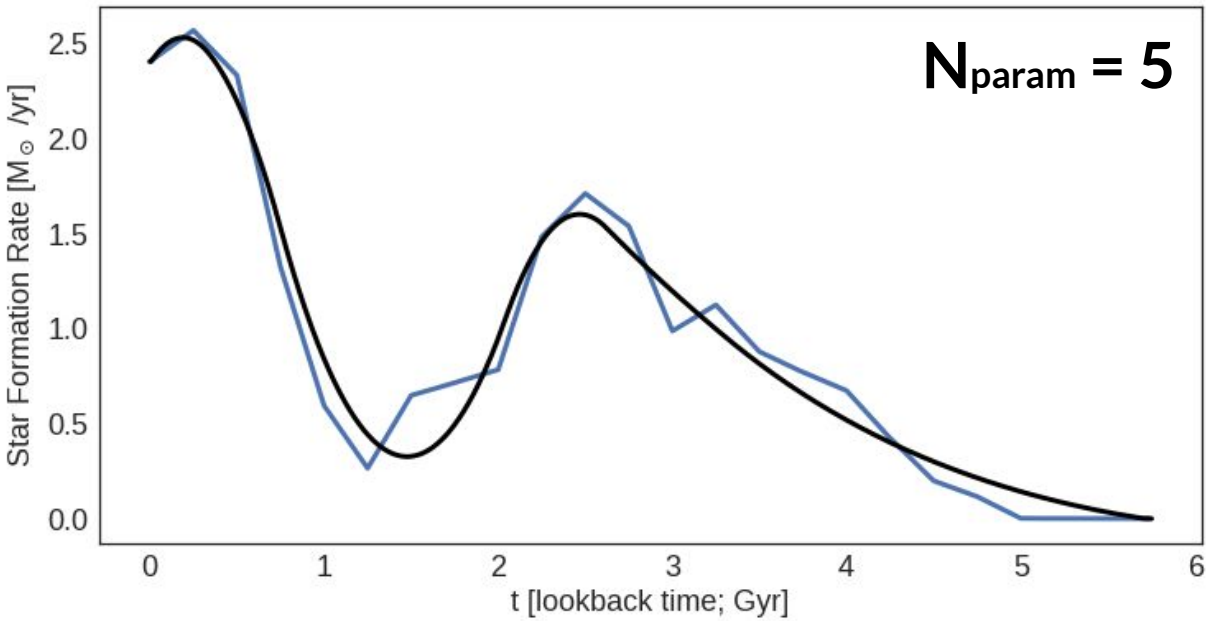

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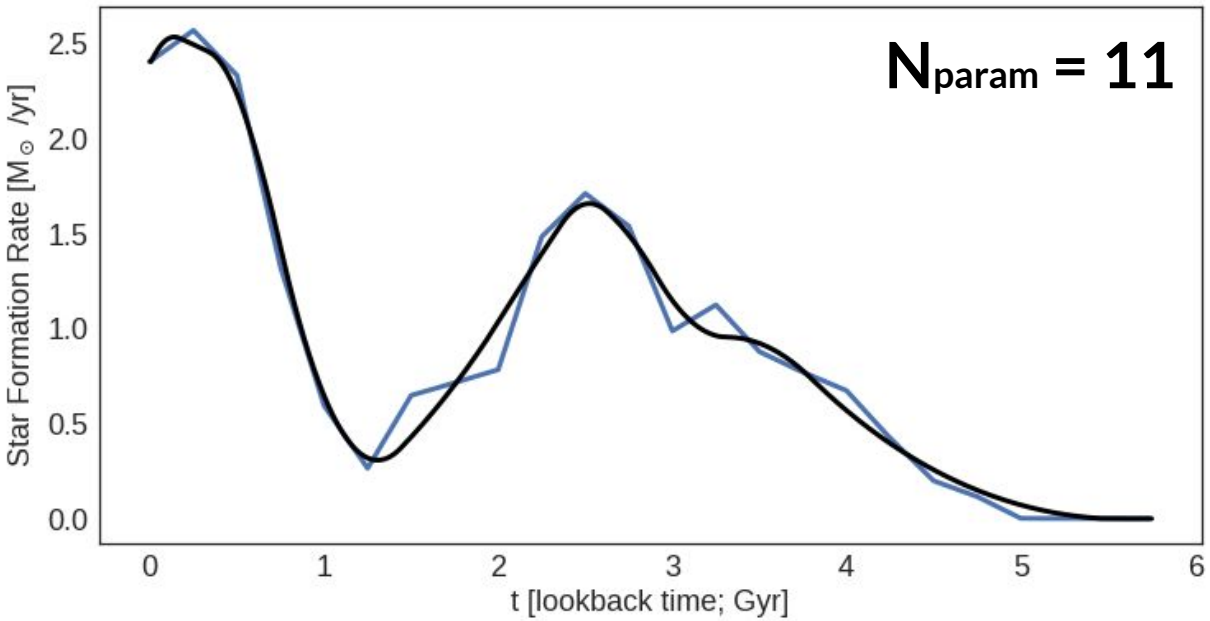

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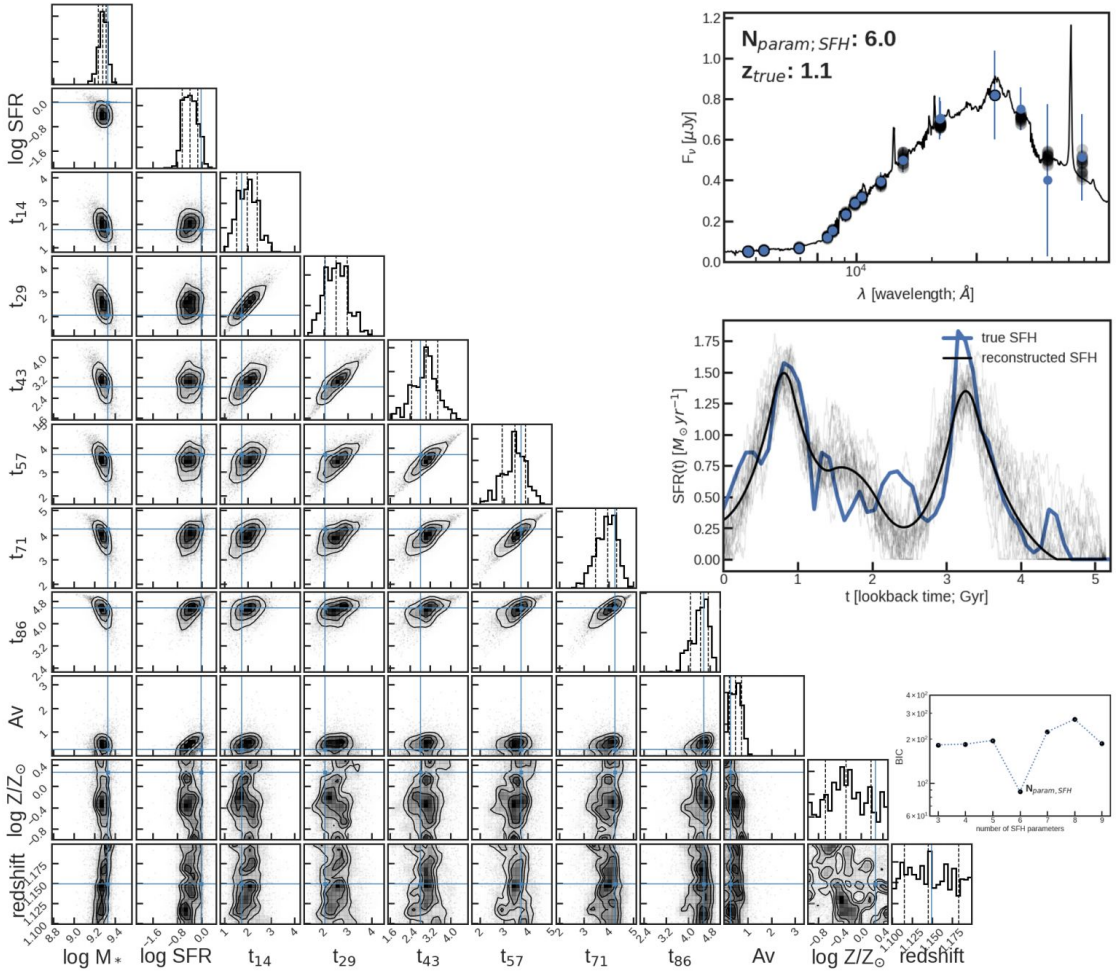
Dense Basis v2.0:
SED fitting example

Full posteriors include
SFH (M*, SFR, [t_x]),
dust, metallicity, redshift



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Summary

The integrated light from galaxies contains a lot of information that we use to understand galaxy evolution, including redshift (z), Stellar Mass (M*), Star Formation Rate (SFR), Age and star formation history (SFH), Chemical abundances in stars and ISM, Dust and AGN properties and more...

With principled analysis and intelligent modeling choices, it is possible to maximise the amount of information extracted from each SED.

Iyer & Gawiser '17, Iyer+19