# Understanding the Circum-galactic Medium by Emulating Extended Lyman Alpha Halos

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A Model To Reveal CGM Physical Properties By Fitting Observed Lya Surface Brightness Profiles

1. Introduction: *Extended Lya Halos*

MUSE#6297 z=3.70 HST F814W

Lya NB Leclercq+2017
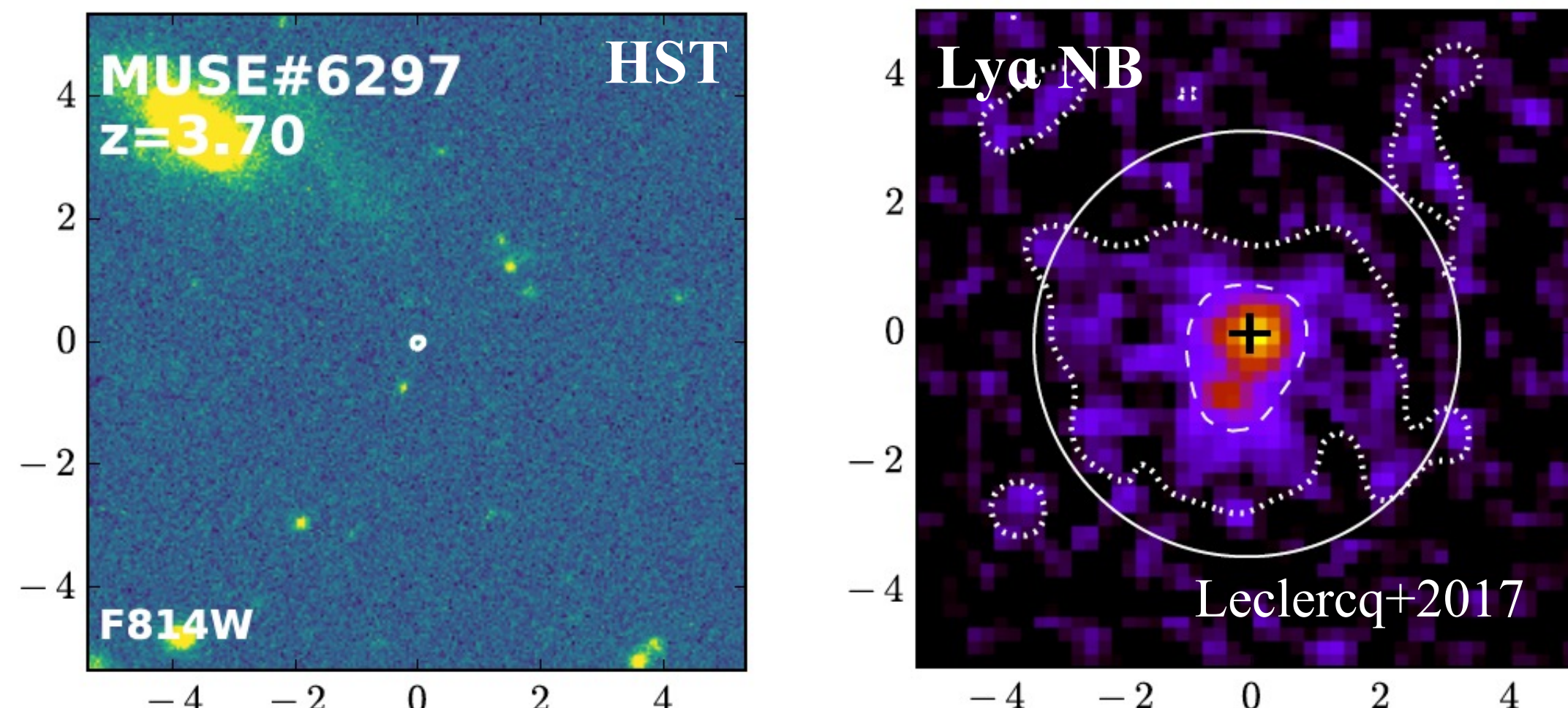
- Extended Lyα Emission at CGM scale, even larger. (Steidel+2011, Momose+2014)
- Observed as Lyα Surface Brightness (SB) Profiles.
- Resonant Scattering between Lyα photons and HI atoms
  ➔ Lyα emission carries information on HI gas properties.

2. Model: *A Physical Model for Surface Brightness Profiles of Extended Lya Halos*

Model Recipes:
- **HI Gas Profiles**: Density+Velocity+ Temperature+Ionization
- **Lya Sources**: Central Galaxy+CGM Recombination+Satellite Galaxy
- **Lya Radiative Transfer (RT)**

HI Gas — Satellite — Central — Lya Radiative Transfer
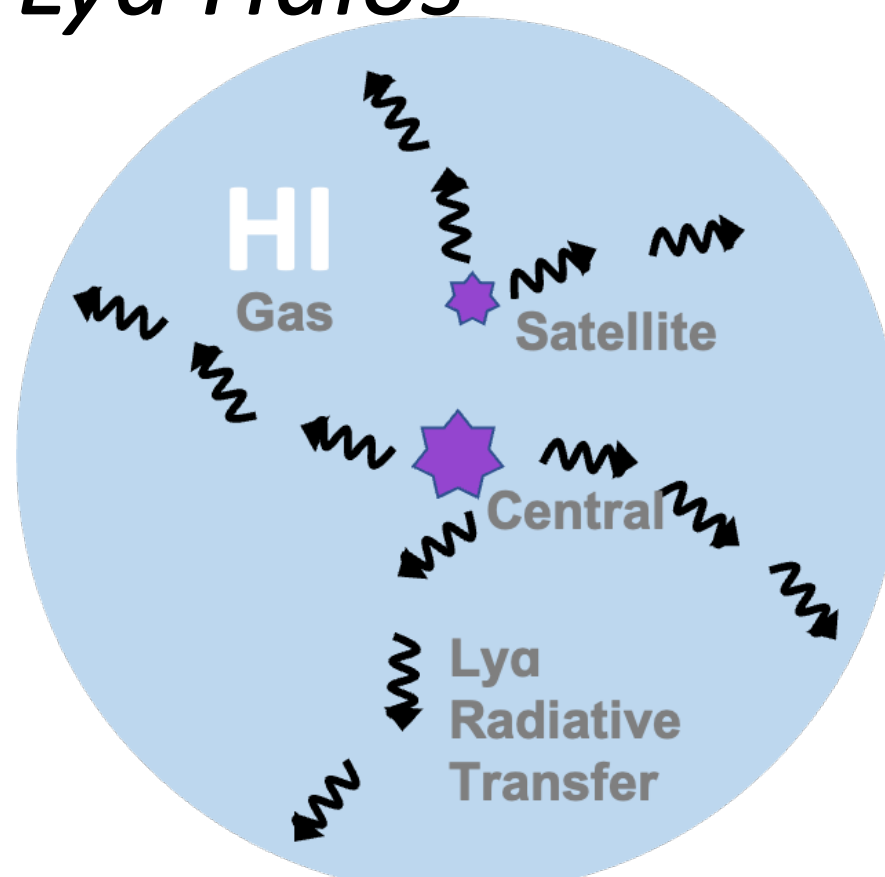
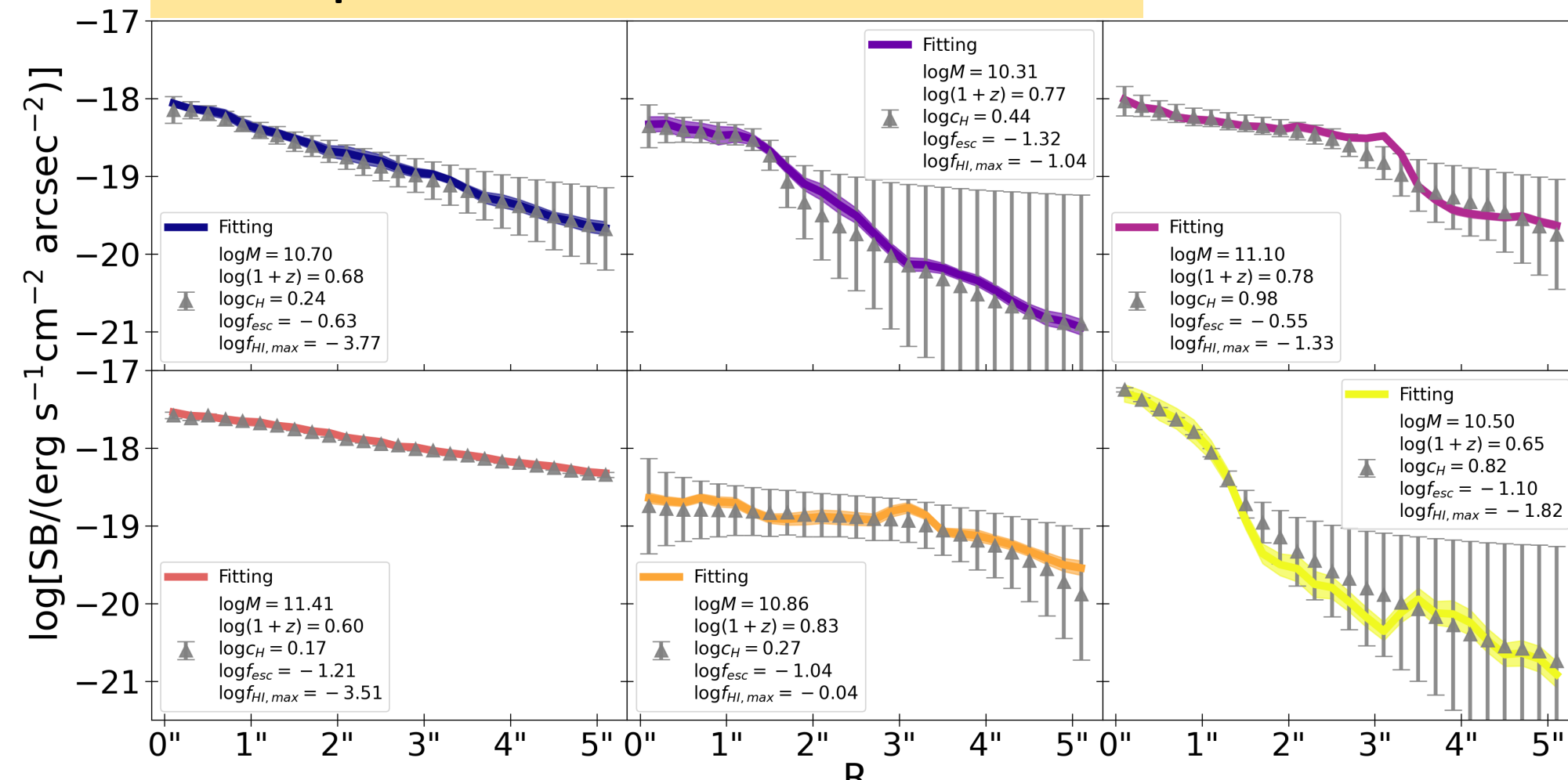| M	z	c_H	f_{esc}	R_{sp}	θ_{obs}	$f_{HI,max}$	f_{cs}
Halo Mass	Redshift	Hydrogen Gas Concen- tration	Ionizing Photon Escaping Fraction	Projected Sat Location	Observing Angle for Sat	Maximum Neutral Hydrogen Fraction	Ratio of Sat to Cen Luminoisty

3. Emulator: *Fast Prediction of Surface Brightness Profiles for a Given Model*

RT Simulation → (Gaussian Process Regression) → Emulator

Slow / Fast

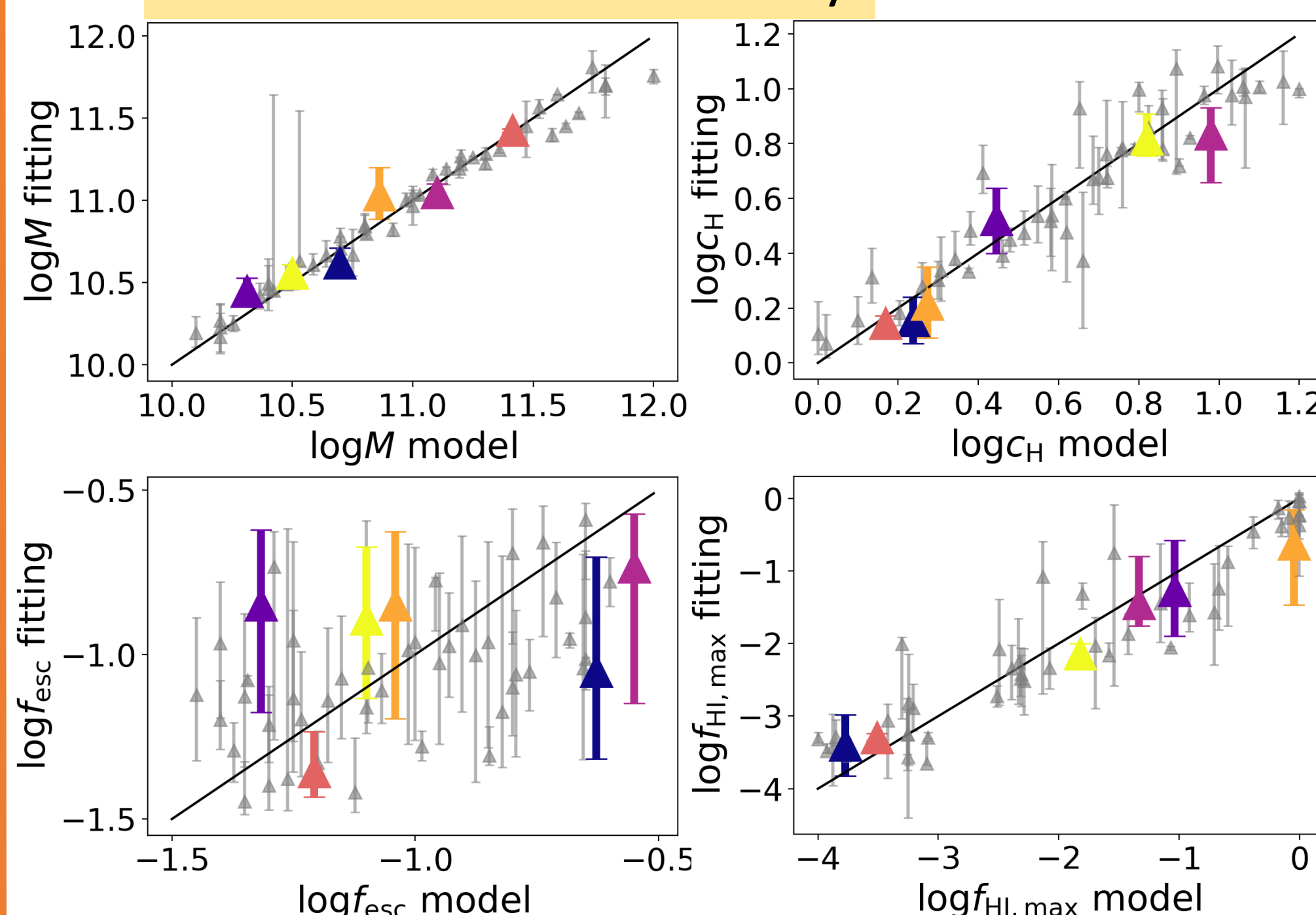Model Parameters ⇄ Surface Brightness Profiles
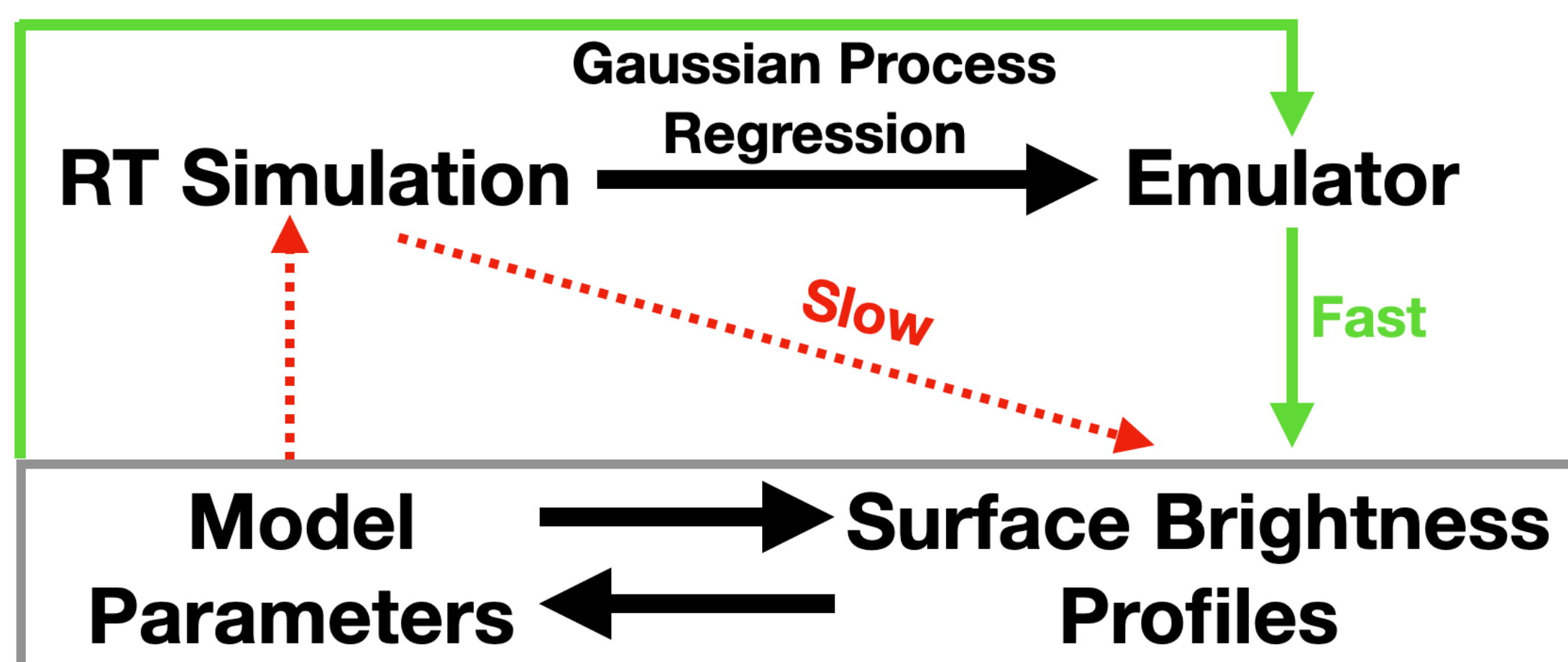
- The emulator is based on **Gaussian Process Regression.**
- Basic procedure:
  - **Simulating**: Run RT simulations for a set of selected model parameters and calculate the Lyα SB profiles (training profiles).
  - **Training**: Build up correlations among training profiles based on their model parameters.
  - **Predicting**: For given model parameters, interpolate training profiles based on the correlations above.

4. Fit Simulated Profiles: *A Monte Carlo Search in Model Parameter Space*
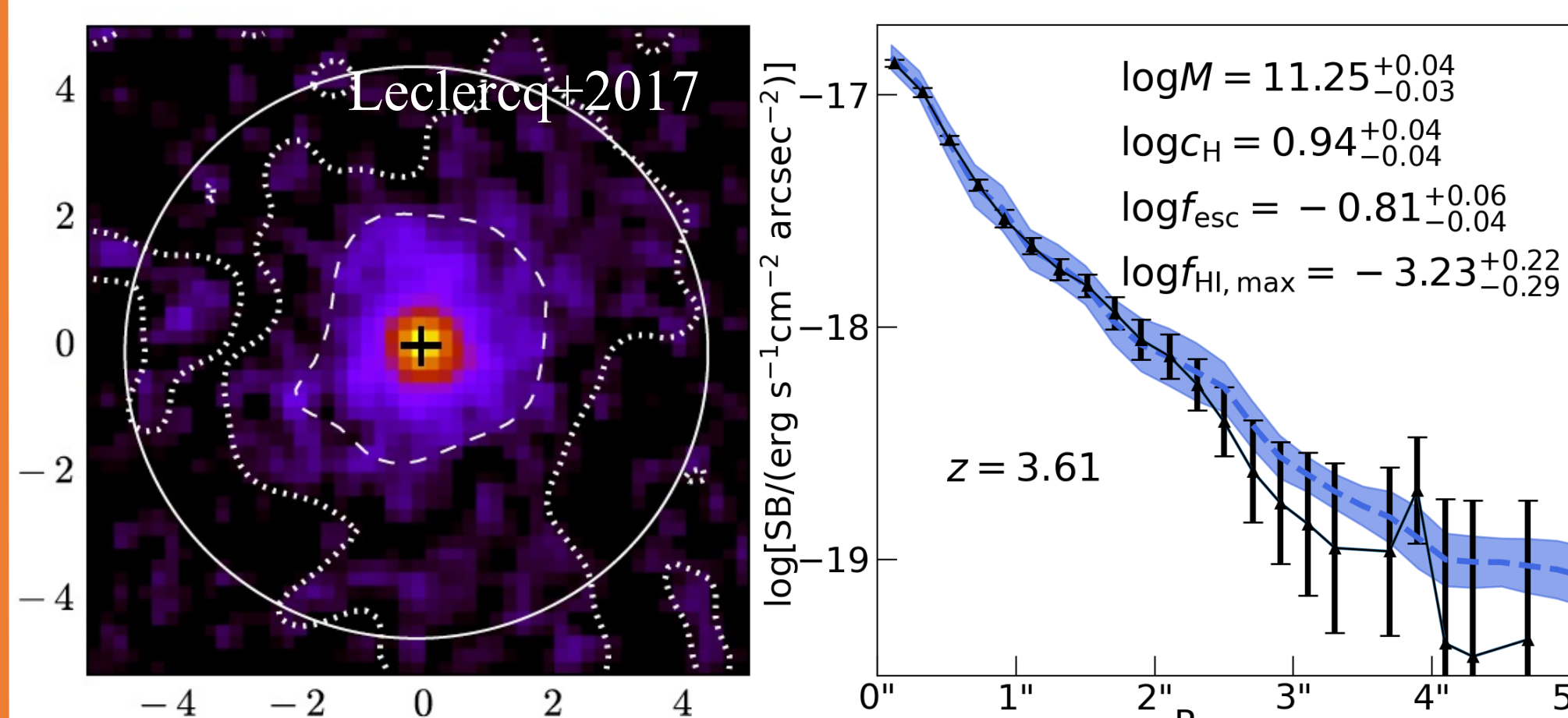
Example Mock Profiles and Fits

Fitting
$\log M = 10.70$
$\log(1+z) = 0.68$
$\log c_H = 0.24$
$\log f_{esc} = -0.63$
$\log f_{HI,max} = -3.77$

Fitting
$\log M = 10.31$
$\log(1+z) = 0.77$
$\log c_H = 0.44$
$\log f_{esc} = -1.32$
$\log f_{HI,max} = -1.04$

Fitting
$\log M = 11.10$
$\log(1+z) = 0.78$
$\log c_H = 0.98$
$\log f_{esc} = -0.55$
$\log f_{HI,max} = -1.33$

Fitting
$\log M = 11.41$
$\log(1+z) = 0.60$
$\log c_H = 0.17$
$\log f_{esc} = -1.21$
$\log f_{HI,max} = -3.51$

Fitting
$\log M = 10.86$
$\log(1+z) = 0.83$
$\log c_H = 0.27$
$\log f_{esc} = -1.04$
$\log f_{HI,max} = -0.04$

Fitting
$\log M = 10.50$
$\log(1+z) = 0.65$
$\log c_H = 0.82$
$\log f_{esc} = -1.10$
$\log f_{HI,max} = -1.82$

Model Parameter Recovery

5. Fit Observed Profiles

Model fitting with Central and CGM Lya sources.

Leclercq+2017

$\log M = 11.25^{+0.04}_{-0.03}$
$\log c_H = 0.94^{+0.04}_{-0.04}$
$\log f_{esc} = -0.81^{+0.06}_{-0.04}$
$\log f_{HI,max} = -3.23^{+0.22}_{-0.29}$
$z = 3.61$

Add a satellite Lya source to address the satellite feature in observed SB profiles.

Kusakabe+2022

$\log M = 10.50^{+0.04}_{-0.04}$
$\log c_H = 0.23^{+0.03}_{-0.03}$
$\log f_{esc} = -1.44^{+0.08}_{-0.04}$
$\log f_{HI,max} = -3.04^{+0.18}_{-0.19}$
$\log R_{sp} = 0.40^{+0.02}_{-0.02}$
$\mu_{obs} = 0.57^{+0.08}_{-0.05}$
$\log f_{cs} = -0.46^{+0.10}_{-0.13}$
$z = 3.02$