Classification of Supernovae

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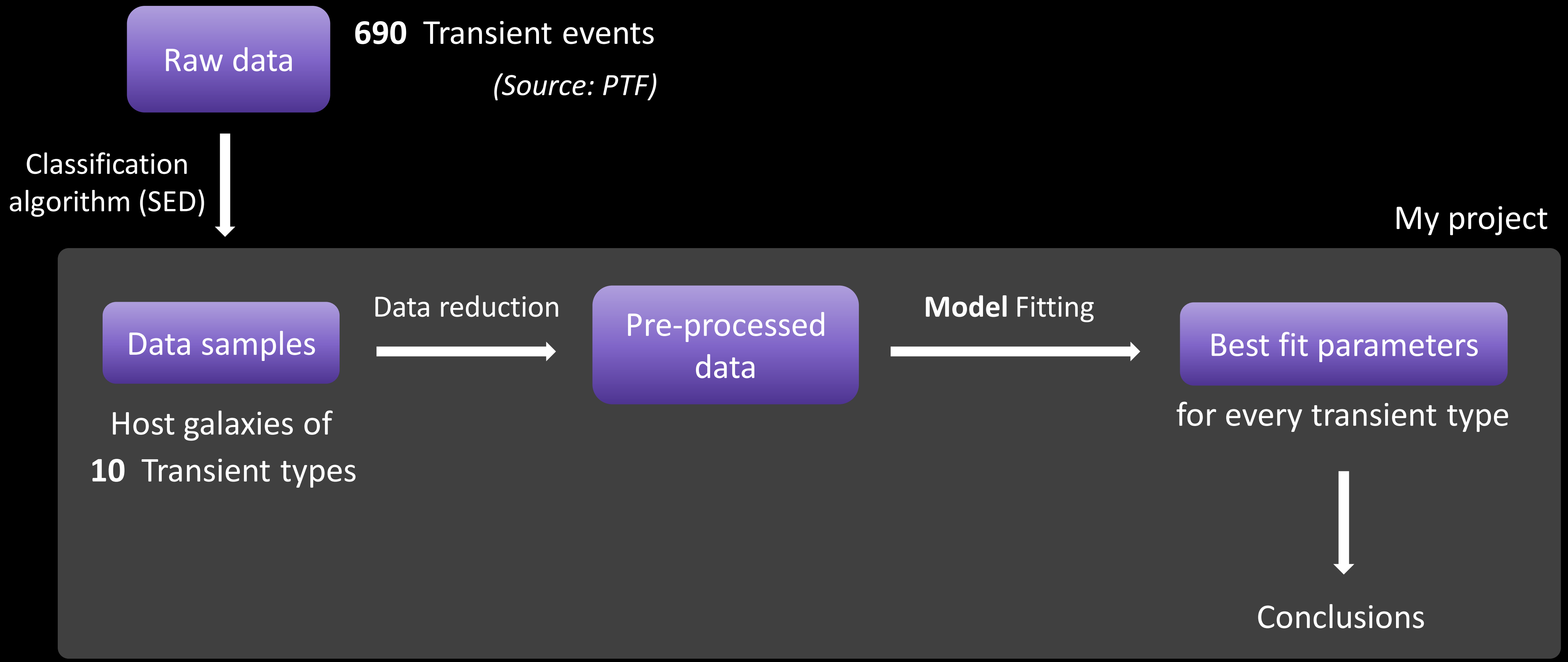
Goal

Which supernovae **types** can we classify by their host galaxy **mass distributions**?

Project outline



Data organization

Transient types

SNIb
SNIc
SNIc-BL
SNIbn
SNII →
SNIIb
SNIIn
SLSN-I
SLSN-IIn
GRB

10

Objects

PTF09axi →
PTF09fqa
PTF10ehy
PTF11jgp
PTF12gcx
⋮

~ Dozens

(Host galaxy)
Mass distribution

=

Mass values

(Host galaxy) Mass	Probability
9.91671180725	2.60337117197e-07
9.74561214447	2.06141994568e-05
9.82774162292	0.000296088197501
9.56758975983	0.00087340985192
9.52915382385	0.00168778956868
⋮	⋮

~ 1000

690 objects with (host galaxy) **mass distributions**

Data reduction – Sampling (bootstrapping)

For each object

PTF09axi

(Host galaxy) Mass	Probability
9.91671180725	2.60337117197e-07
9.74561214447	2.06141994568e-05
9.82774162292	0.000296088197501
9.56758975983	0.00087340985192
9.52915382385	0.00168778956868
⋮	⋮

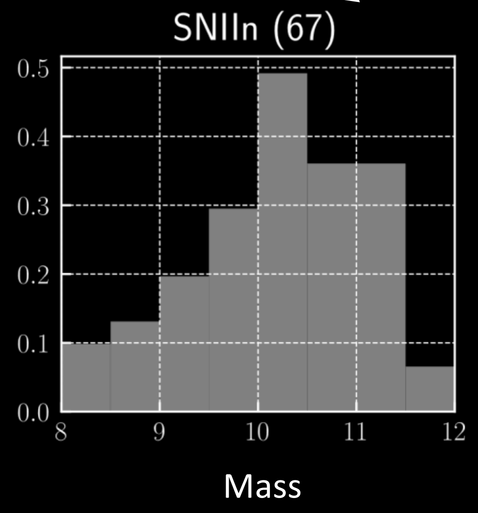
random sampling of **one** mass value

9.569153

Data reduction

For **1** transient type

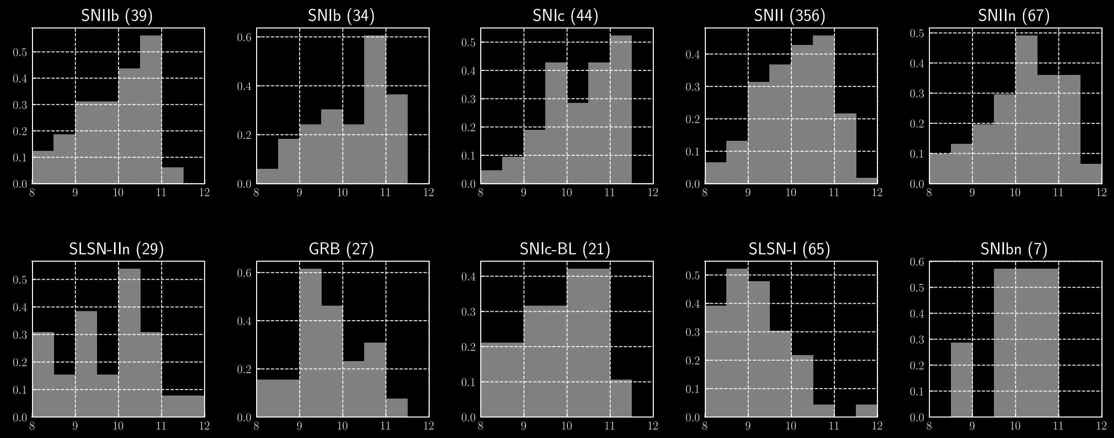
# of objects



Data reduction – Sampling (bootstrapping)

Mass distributions of host galaxies

Transient type (# of objects)

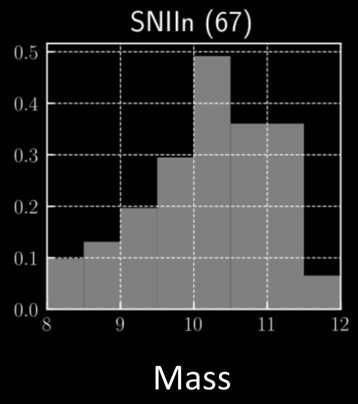


Mass

= **1** bootstrap sample

Model

Mass distribution of host galaxies



= Number of **galaxies** per mass × Number of **events** per galaxy

Galaxy's mass function
$\Phi(M)$

Galaxy's star formation rate
$\mathrm{SFR}(M)$

Mass function $\Phi(M)$

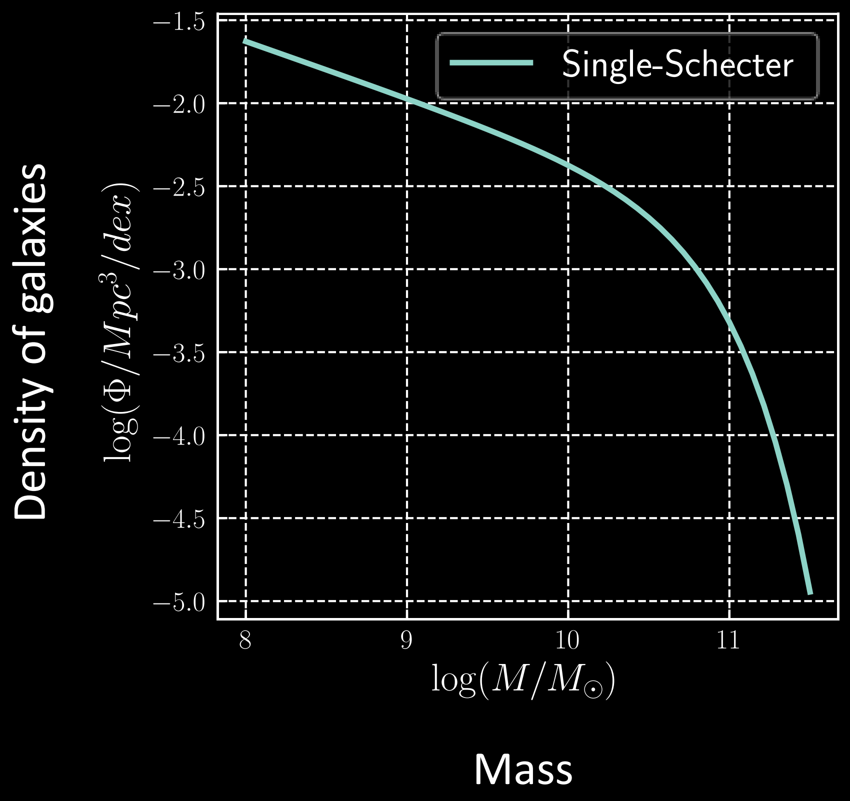
Number **density** of galaxies as a function of their **mass**.

<u>The single-Schechter function (1976)</u>

$$\Phi(M)dM = \ln(10) \cdot \Phi^* \cdot 10^{(1+\alpha)(\log M - \log M^*)} \cdot \exp\left(-10^{(\log M - \log M^*)}\right) dM$$

$\log M^*$	Φ^*	α
10.81	$11.34 \cdot 10^{-4}$	-1.34

Muzzin et al. (2013)



Star formation main-sequence (SFR)

The relationship between a galaxy's **star formation rate** (SFR) and its stellar **mass**.

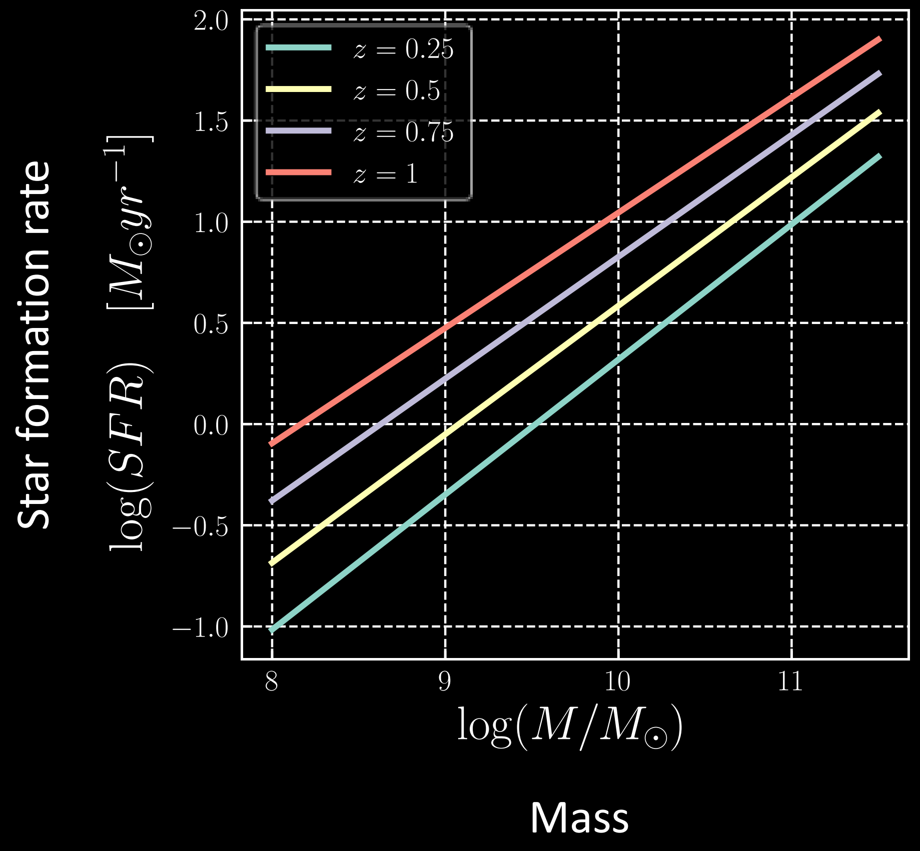
$$\log(\mathbf{SFR}) = \alpha(z)(\log(\boldsymbol{M}) - 10.5) + \beta(z)$$

$$\alpha(z) = 0.70 - 0.13z$$

$$\beta(z) = 0.38 + 1.14z - 0.19z^2$$

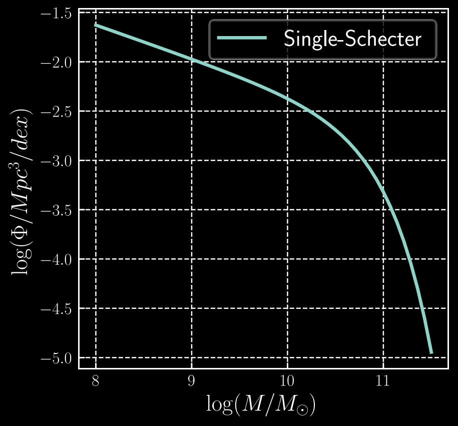
z - redshift

Whitaker et al. (2014)



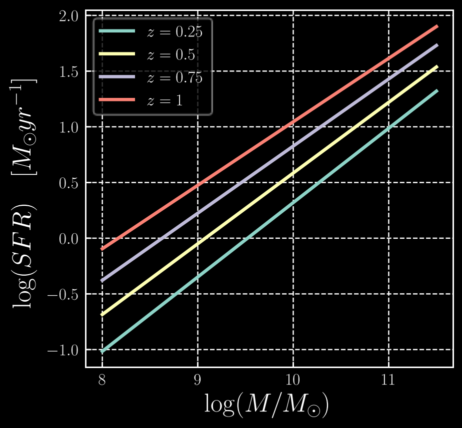
The mass function weighted by SFR

Mass function



×

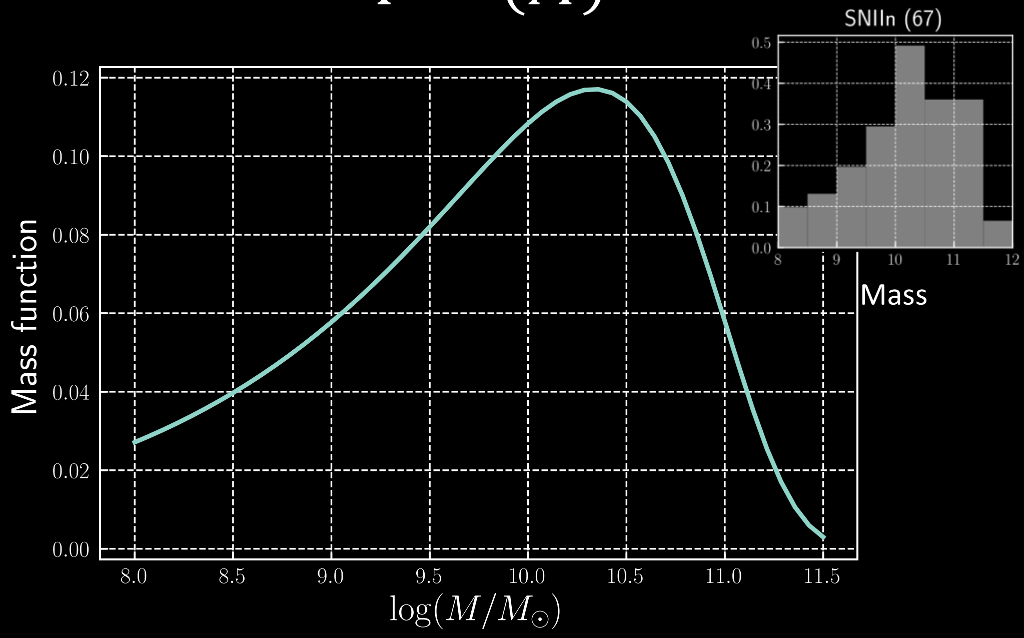
Star formation rate



$(z = 0.2)$

=

$\Phi^{\mathrm{SFR}}(M)$



How to differentiate between transient types?

Star formation efficiency function

$$\Phi^{\mathrm{SFR}}(M) \longrightarrow \underbrace{\rho(M; M_0, \beta. C)}_{\text{efficiency}} \cdot \Phi^{\mathrm{SFR}}(M)$$

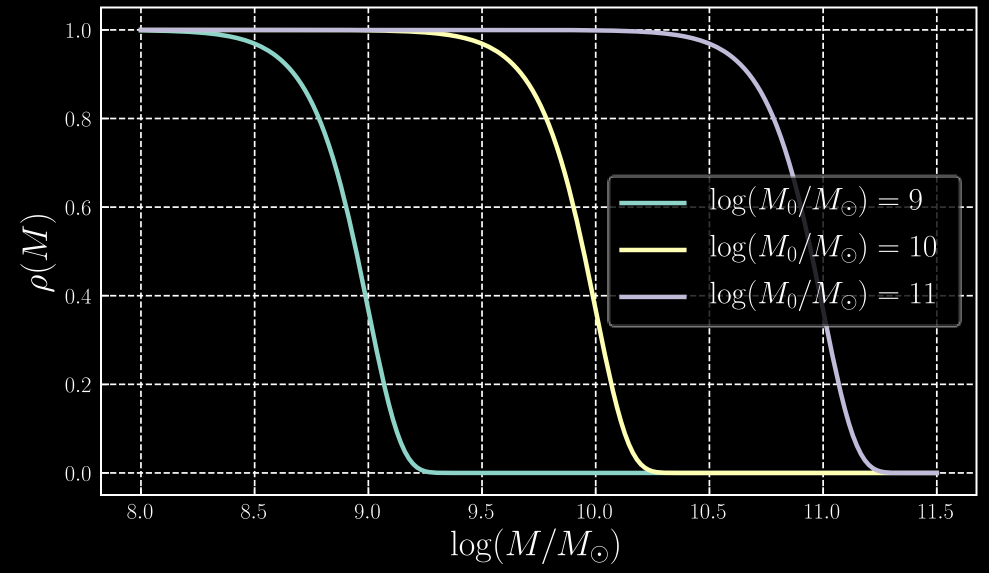
$$\rho(M; M_0, \beta, C) = C \exp\left\{-\left(\frac{M}{M_0}\right)^{\beta}\right\}$$

M_0 cut-off mass

β cut-off strength

C fudge factor

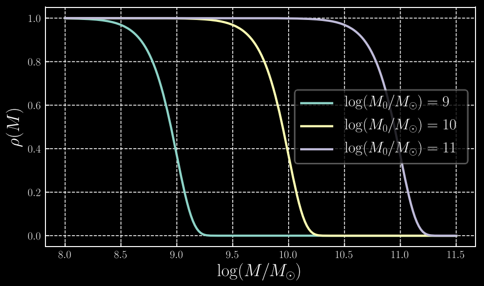
Efficiency function

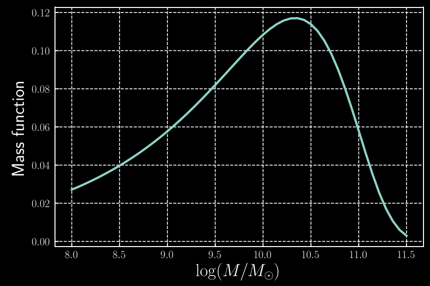


Mass

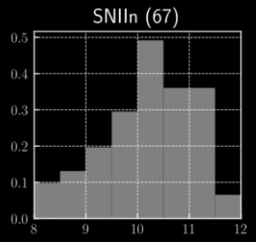
Final expression of the model

$$\text{Mass distribution} = \rho(M; M_0, \beta, C) \cdot \Phi^{\mathrm{SFR}}(M)$$





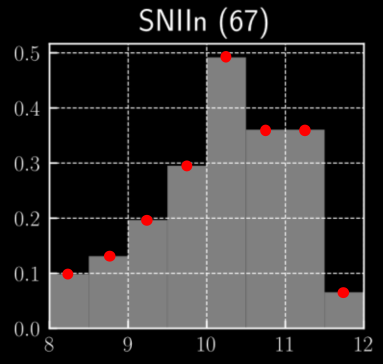
Model **fitting** to

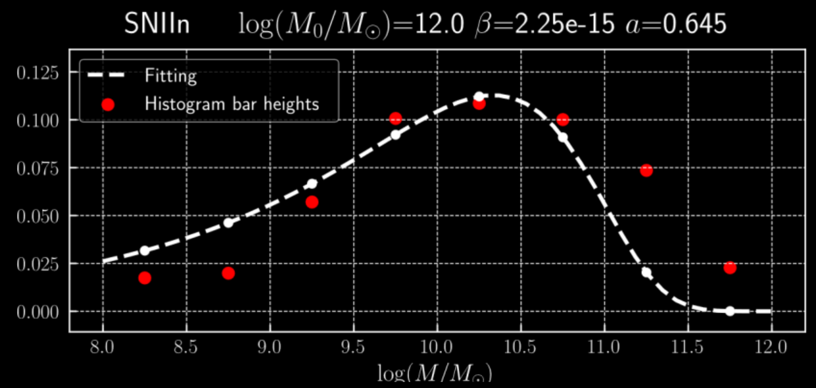


with 3 free parameters: M_0, β, C

Model fitting

Fitting the cut-off mass M_0 and strength β

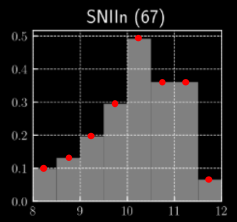




1 pair of values for M_0 and β

with random bin centers

Labeling unsuccessful fitting



fit

fit

(There is a cut-off mass) $\rho(M; M_0, \beta. C) \cdot \Phi^{\mathrm{SFR}}(M)$

$\Phi^{\mathrm{SFR}}(M)$ (No cut-off mass)

MSE_1 mean squared error MSE_0

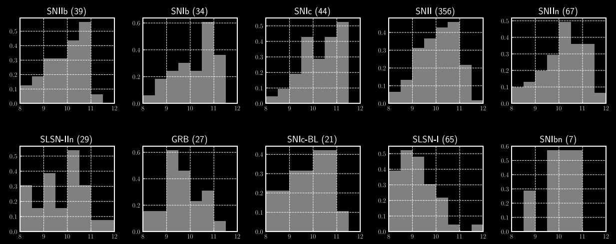
<u>Successful fitting</u>

$$\mathrm{MSE}_1 < \mathrm{MSE}_0$$

Using **1** bootstrap sample

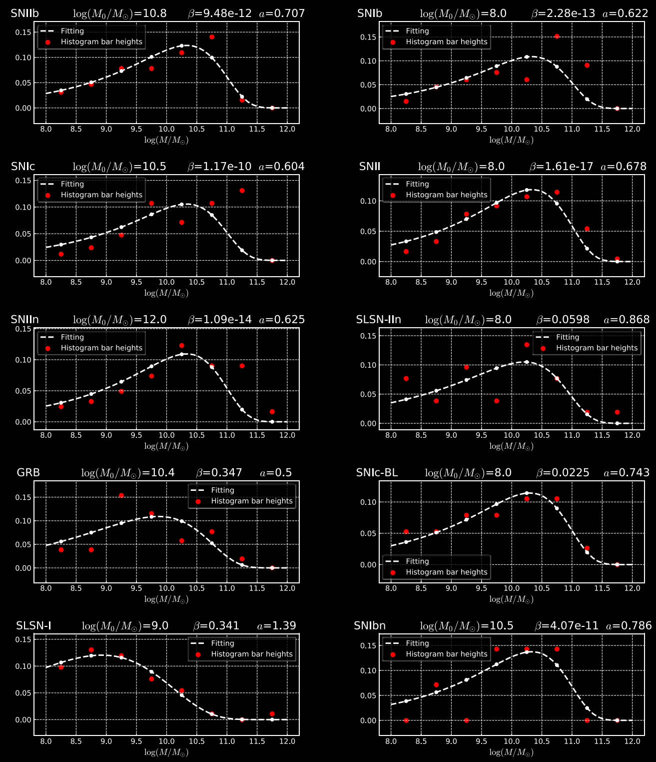
1 bootstrap sample

Transient type (# of objects)



Mass

Fitting for every transient type



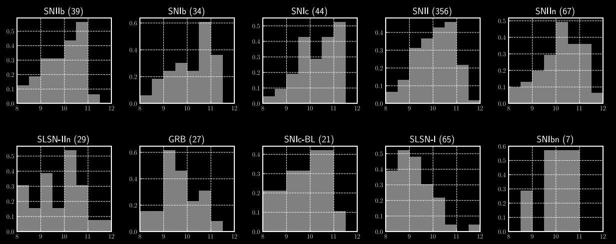
For every transient type:

1 pair of values for M_0 and β

Using **N** bootstrap sample

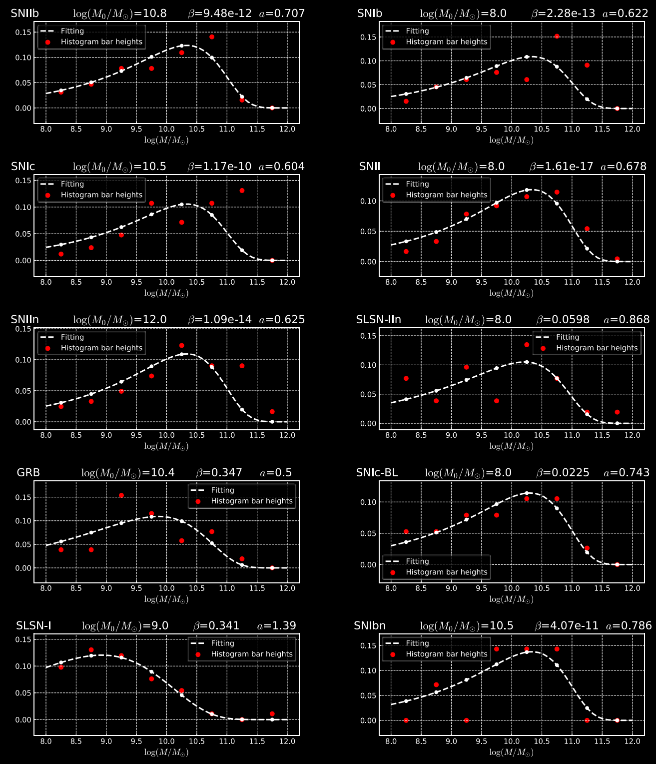
N samples

Transient type (# of objects)



Mass

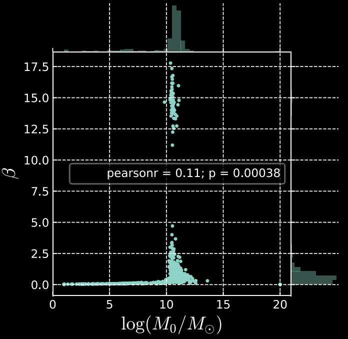
Fitting for every transient type



For every transient type:

N pairs of values for M_0 and β

β

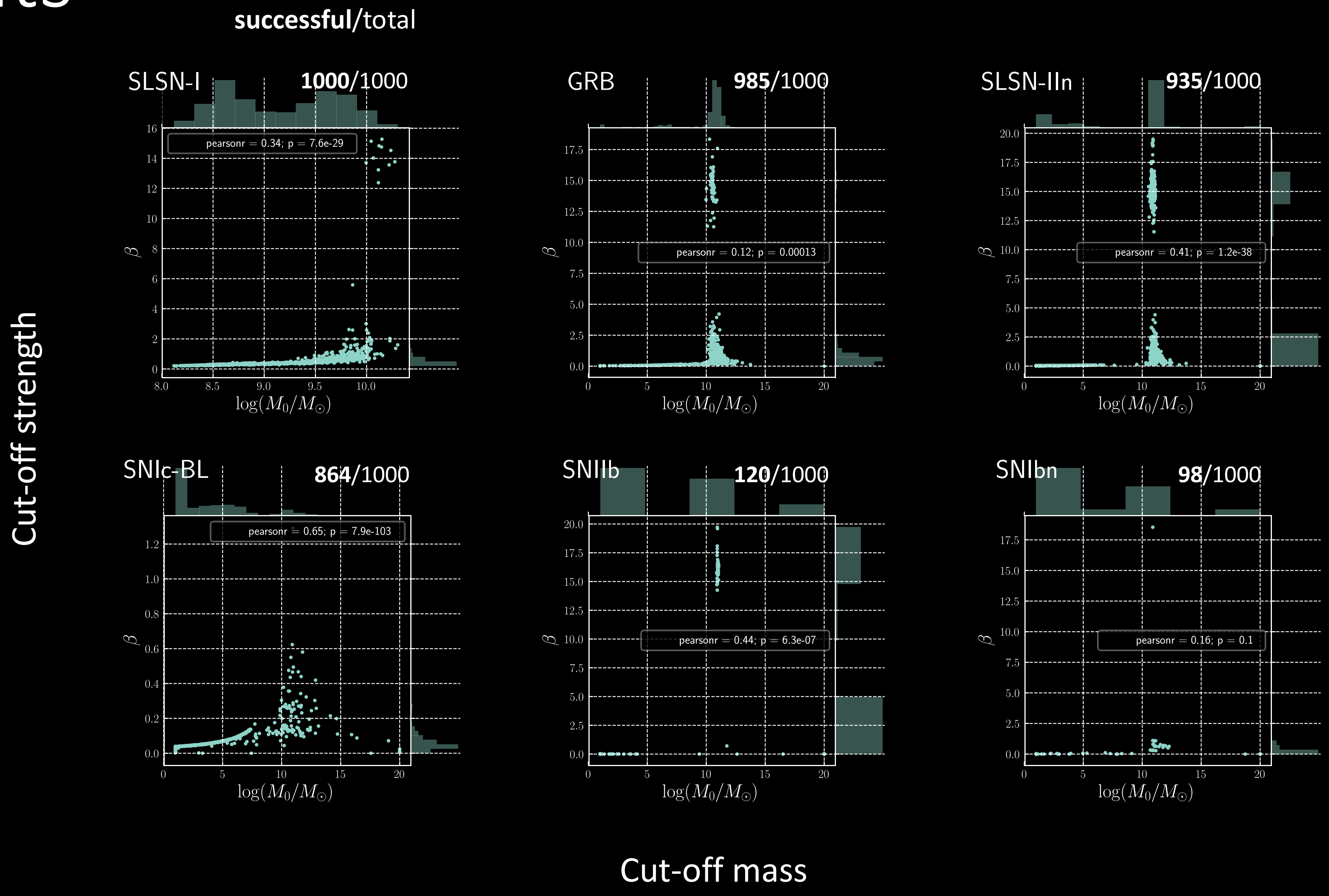


M_0

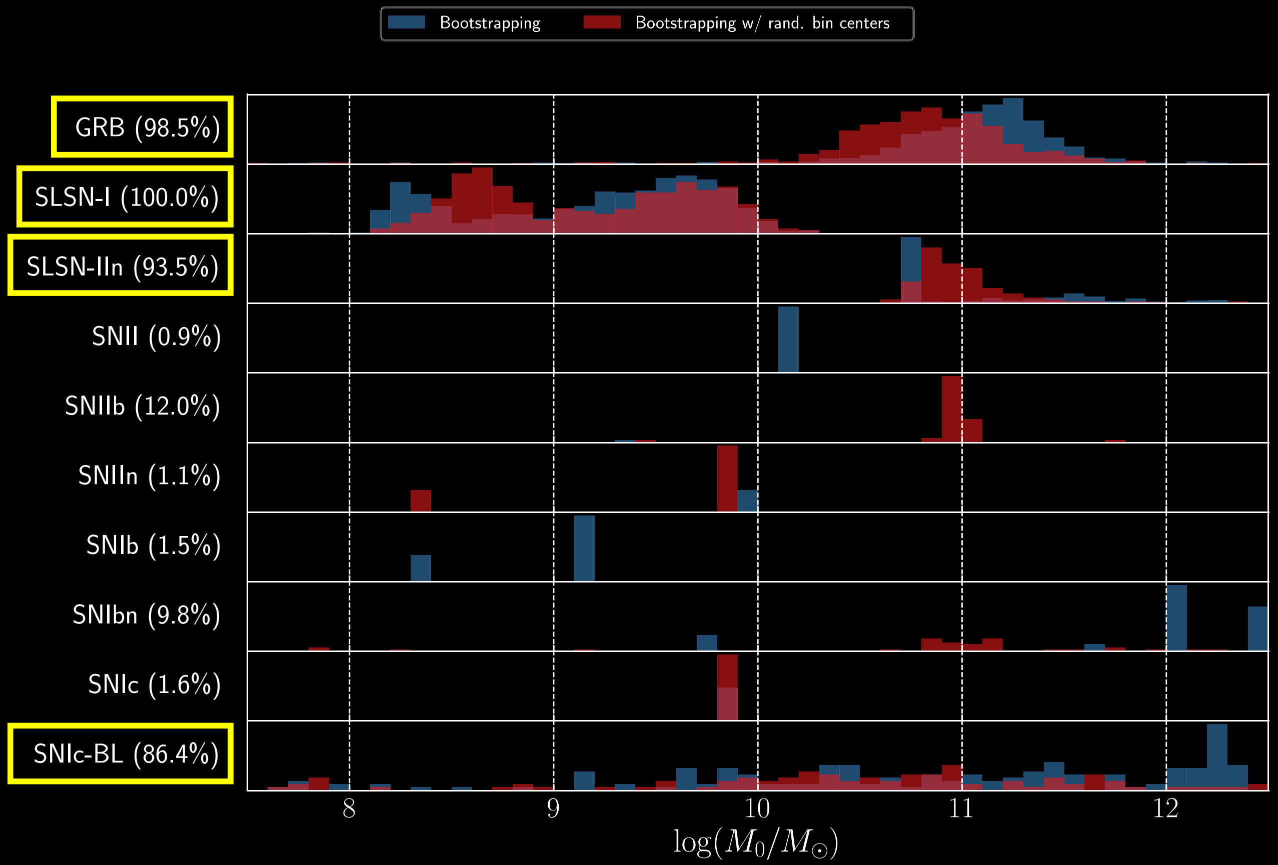
Model fitting - Results

Fitting results

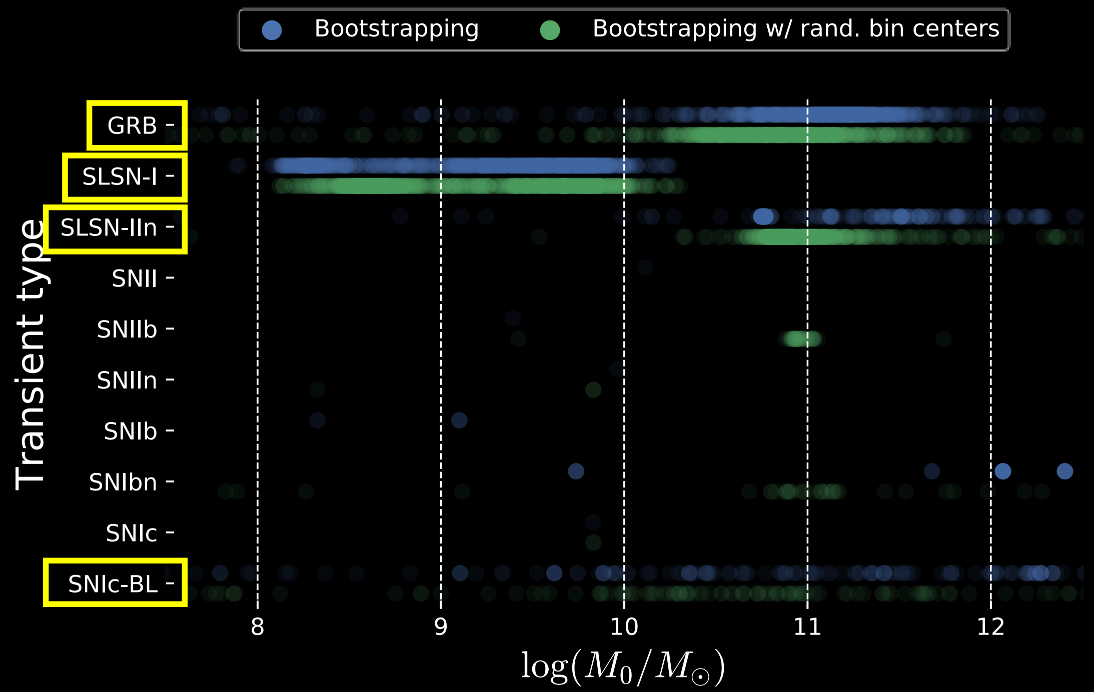
1000
bootstrap samples



Fitting results – Cut-off mass M_0



Cut-off mass



Cut-off mass

Summary

- Data analysis – creating python package and notebook

- Results:
  - Only 4 transient types show prominent suppression at high mass galaxies:

    SLSN-I, SLSN-II, GRB, SNIc-BL
  - Cut-off metallicity can be calculated using mass-metallicity relation

- Further directions:
  - Deriving hypothesis testing – H_0, H_1 will have different M_0 values, where $\ln \mathcal{L}(M_0) = \sum_{i=1}^{n} \ln \Phi^{\mathrm{SFR}}(m_i|M_0)$
  - Using different data - luminosity instead of mass
  - Re-estimation when new data arrives