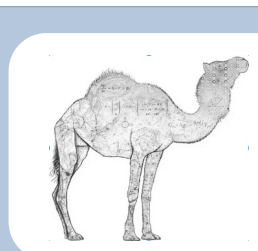
Modelling the Cosmology and Astrophysics Dependent Galaxy-Halo Relationship using Normalizing Flows and the CAMEL Simulations



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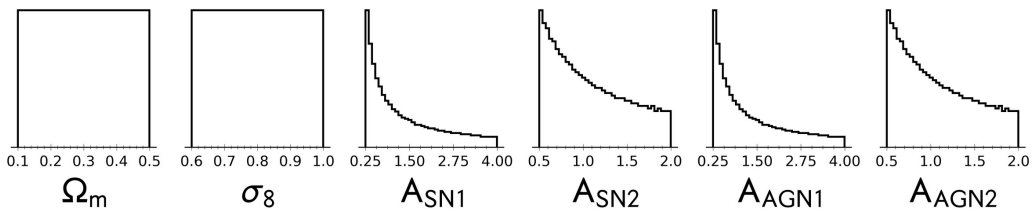
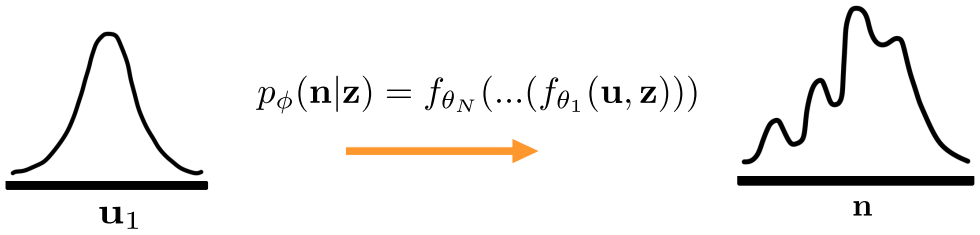
$$\mathbf{z} = \{\Omega_{\rm m}, \sigma_8, A_{\rm SN1}, A_{\rm SN2}, A_{\rm AGN1}, A_{\rm AGN2}\}$$



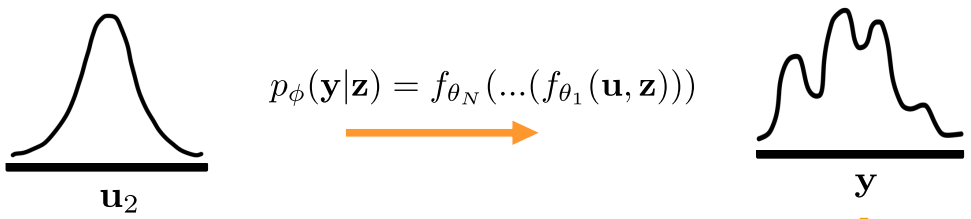
Abundance Flow

$\mathbf{n} = \{N_{\rm halo}\}$



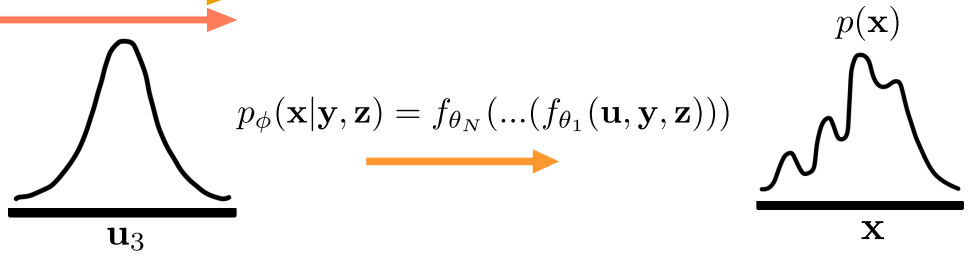
Halo Flow

$\mathbf{y} = \{M_{\rm halo}\}$



Galaxy Flow

$\mathbf{x} = \{M_\star, {\rm SFR}, M_{\rm gas}, M_\bullet\}$



We present a unified model of the conditional dependence of galaxy properties on cosmological, astrophysical and host halo parameters.

Using a large sample of galaxies taken from the **Cosmology and Astrophysics with MachinE Learning Simulations (CAMELS)** project, a suite of hydrodynamic simulations varying both cosmological and astrophysical parameters, we train a **normalizing flow (NF)** to map the probability density of various galaxy and halo properties.

We train two flows to model the abundance and distribution of halo masses. We condition on $\Omega_{\rm m}$ and σ_8, as well as two parameters describing the strength of supernovae feedback, and two describing the strength of AGN feedback.

We then train a final flow to model host galaxy properties, simultaneously conditioned on the host subhalo mass of each galaxy.

The model successfully reproduces the joint and conditional dependence of various galaxy parameters, and by leveraging the learnt conditional relationships we can explore a wide range of interesting questions, whilst enabling simple marginalisation over nuisance parameters.

The NF architecture allows for rapid sampling and scoring. The former allows us to treat the model as a **generative model;** we demonstrate this by using the conditional dependence on subhalo mass to map galaxies to dark matter haloes in N-body simulations, reproducing the galaxy stellar mass function (GSMF), and including the scatter introduced by stochastic sampling

We can also adjust the parameters and explore the effect on distribution functions such as the GSMF. The figure below shows how changing the two parameters controlling supernovae feedback affect the low- and high-mass end of the GSMF. We also self consistently predict the underlying halo mass function using the abundance and halo flows.

We also use the scoring capabilities of the NF to treat the model as an **inference engine,** allowing us to carry out simulation based inference provided the properties of a single galaxy. We are able to rule out large volumes of cosmological parameter space