Galaxy Demographics

and the SkyPy project

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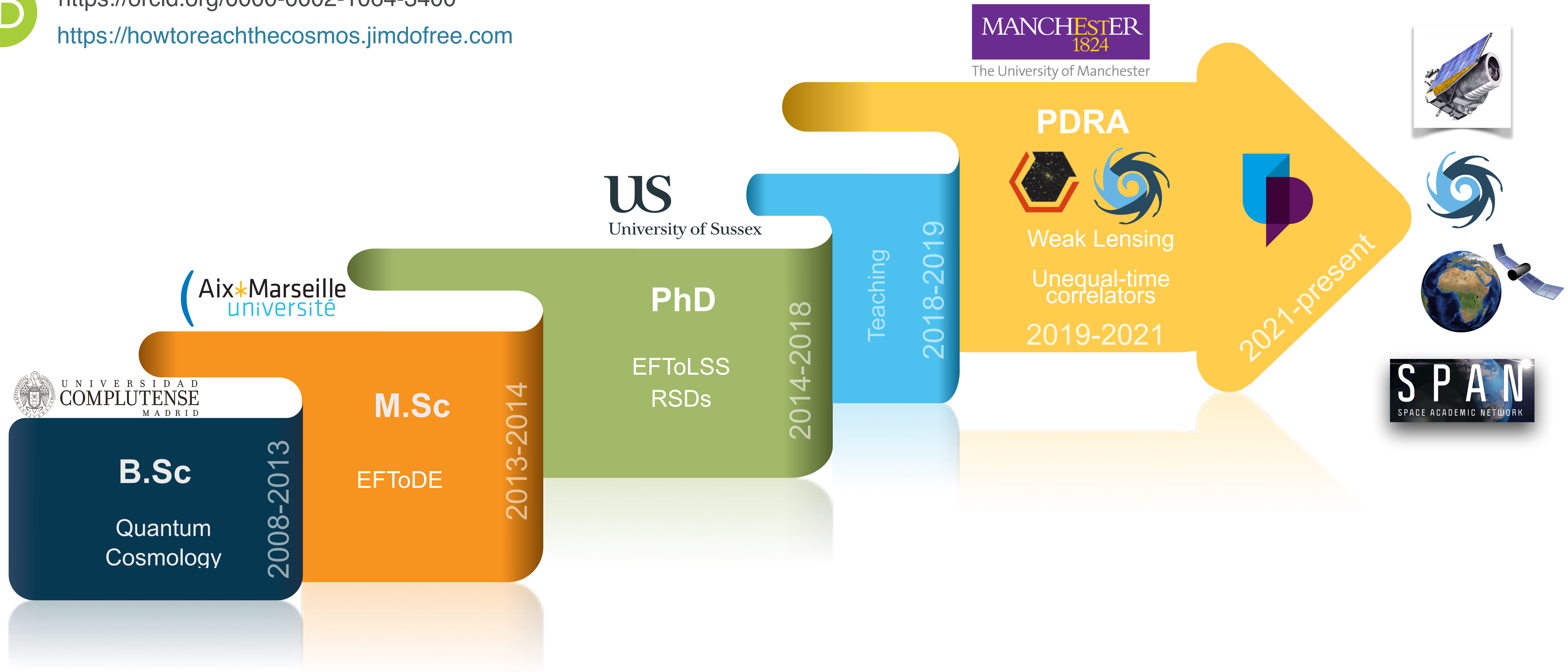
UNIVERSITY OF PORTSMOUTH

Who I am...

https://orcid.org/0000-0002-1064-3400
https://howtoreachthecosmos.jimdofree.com



I. Galaxy Demographics

L. F. de la Bella, A. Amara, S. Birrer, W. Hartley & P. Sudek, arXiv 2112.11110

1. Context and goals
2. Method
3. Validation


Milenium Simulation
James Trayford
Sonification
Virtual Reality

The challenge

Open-data revolution in Astronomy

Sophisticated analysis methods that heavily rely on realistic simulations

Goal: produce realistic simulations faster and more accurately

This work: galaxy populations

Active & **Passive**

Milenium Simulation

James Trayford
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Virtual Reality

SkyPy

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Active & **Passive**

~~Blue & Red~~

James Trayford
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Virtual Reality

Milenium Simulation

Galaxy populations

Tools

Schechter mass function

$$\phi(m,t)dm = \phi_*(t)\left(\frac{m}{m_*}\right)^{\alpha} e^{-m/m_*}dm$$

- Star-forming galaxies $\{\phi_{*b}, \alpha_b, m_{*b}\}$ Star formation rate: $SFR = \frac{dm}{dt} = m\, sSFR$
- Satellite quenched $\{\phi_{*\rho}, \alpha_\rho, m_{*\rho}\}$ Quenching rate: $\eta_\rho \simeq 50\,\%$
- Mass quenched $\{\phi_{*m}, \alpha_{sm}, m_{*m}\}$ Quenching rate: $\eta_m = \frac{SFR}{m_*}$

$\eta \rightarrow$ Probability for isolated active galaxies being quenched per unit time

(Inverse: time scale an isolated active galaxy waits to be quenched)

$f \rightarrow$ Fraction of quenched galaxies

James Trayford
Sonification
Virtual Reality

Milenium Simulation

The goal

Main goal

Produce realistic simulations faster and more accurately

Objectives

1. Write the “passive” **Schechter parameters** in terms of the active population.

2. Derive the **time evolution** of $\phi_*(\mathbf{z})$.

Milenium Simulation

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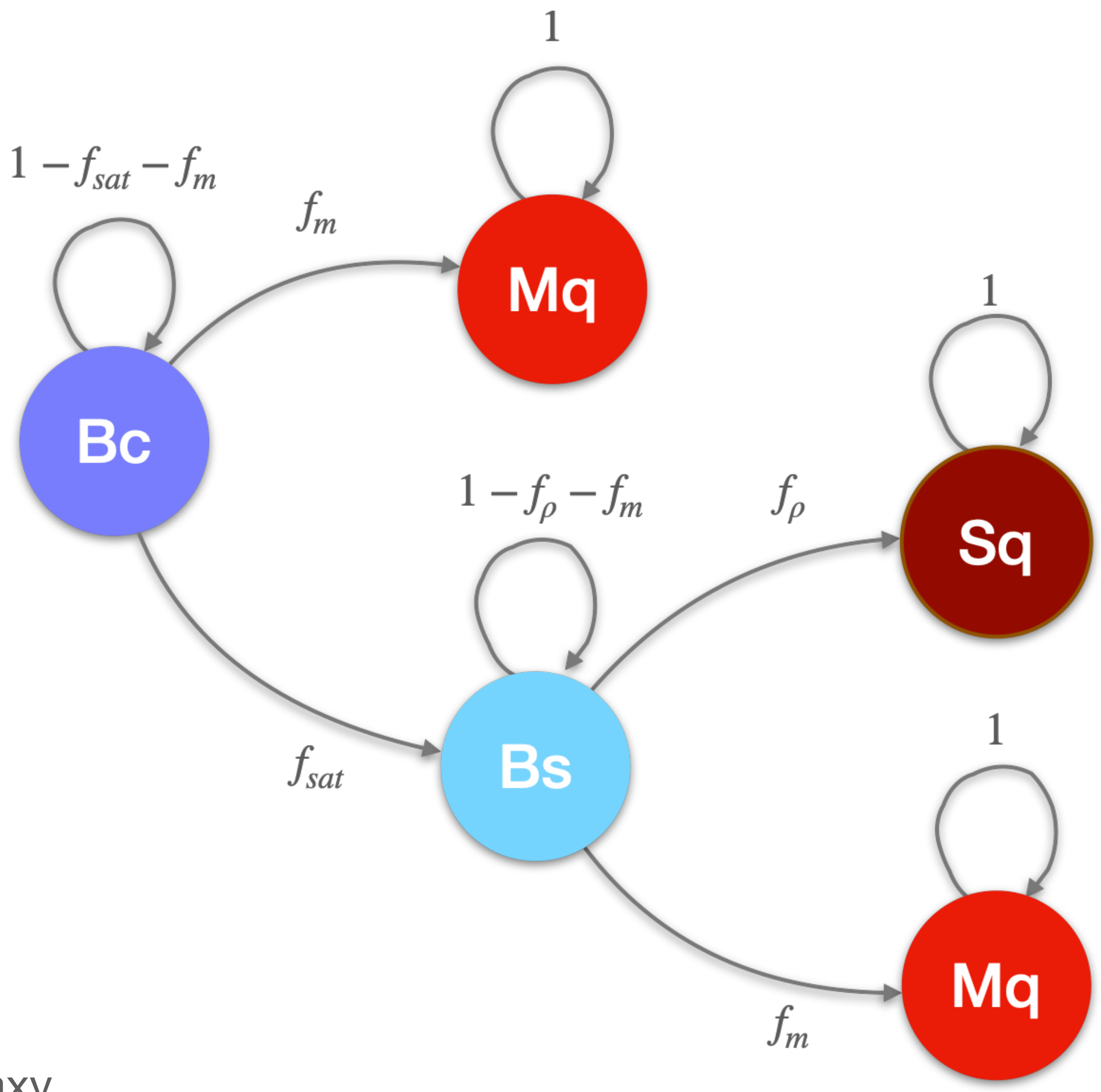
The method

Describe galaxy demographics with a set of continuity equations invoking two quenching mechanisms



$$\frac{dB_c}{dt} = \alpha sSFRB_c - \eta_m B_c - \eta_{sat} B_c$$

$$\frac{dB_s}{dt} = \alpha sSFRB_s - \eta_m B_s - \eta_\rho B_s + \eta_{sat} Bc$$

$$\frac{dM_q}{dt} = \eta_m B_c + \eta_m B_s$$

$$\frac{dS_q}{dt} = \eta_\rho B_s$$

B_c Active central galaxy

B_s Active satellite galaxy

M_q Mass-quenched galaxy

S_q Satellite-quenched galaxy

The results

1. Write the "passive" **Schechter parameters** in terms of the active population.
2. Derive the **time evolution** of $\phi_*(\mathbf{z})$.

Reduce parameter space for simulations
Passive galaxies described by double Schechter function
Satellite-quenched galaxies subset of the active population

Exact analytical time dependence of the amplitude of the active galaxies

	ϕ_*	α	M_*
Star-f	ϕ_b^*	α_b	m_b^*
Sat-q	$F_\rho \phi_{bs}^*$	α_b	m_b^*
Mass-q	$\simeq \phi_b^*$	$\alpha_b + 1$	m_b^*

$$f_\rho = 1 - e^{-\int \eta_\rho dt} \qquad F_\rho = \frac{1}{ln(1 - f_\rho)}$$

$$\begin{Bmatrix} \phi_{*b} & \alpha_b & m_{*b} \\ \phi_{*m} & \alpha_m & m_{*m} \\ \phi_{*\rho} & \alpha_\rho & m_{*\rho} \end{Bmatrix} \longrightarrow \begin{Bmatrix} \phi_{*b} & \alpha_b & m_{*b} \\ f_\rho & f_{\rm sat} & \end{Bmatrix}$$

$$\phi_b(m,t) = B_c(m,t) + B_s(m,t)$$

$$\phi_{*b}(z) = A(\eta_{sat}) e^{f(z;\eta_{sat})}$$

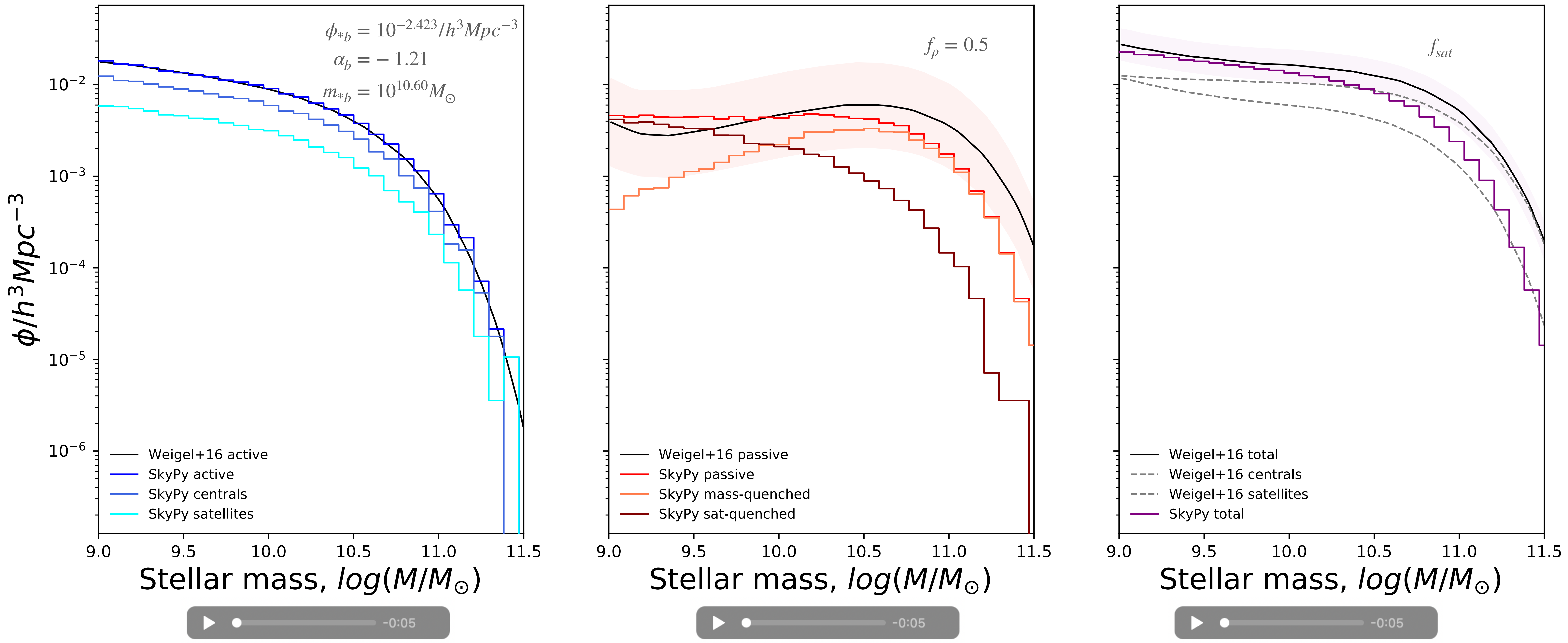
Note:
perform a polynomial expansion and retrieve the Herbel et al.model 2017 $\phi_*(z) = b e^{az}$

Implemented in the SkyPy galaxy module

Validation

Weigel et al. 2016 best-fit for SDSS DR7

Galaxy Demographics Simulation



Example + Sonification with Strauss

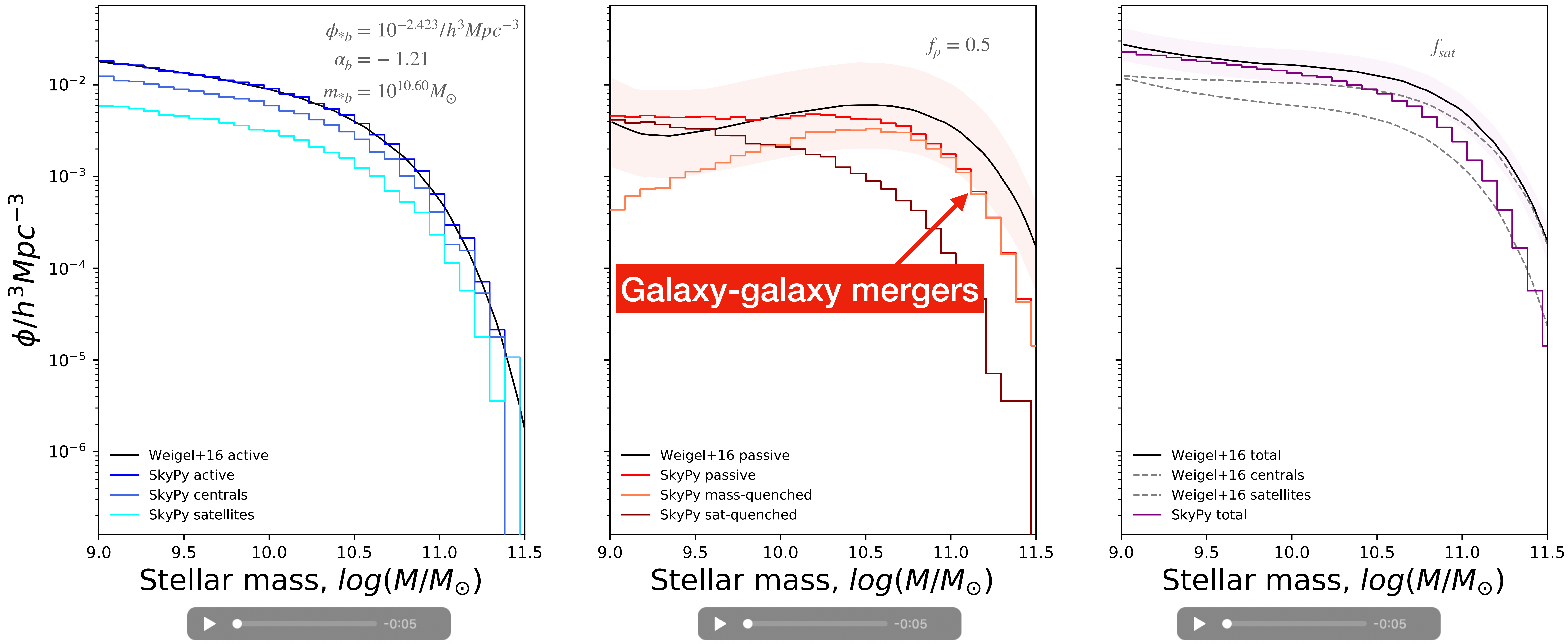
Trayford J., 2021, james-trayford/strauss: v0.1.0

Implemented in the SkyPy example page

Validation

Weigel et al. 2016 best-fit for SDSS DR7

Galaxy Demographics Simulation



Example + Sonification with Strauss

Trayford J., 2021, james-trayford/strauss: v0.1.0

Implemented in the SkyPy example page

Remember

Main goal

Produce realistic simulations faster and more accurately

Method

Describe galaxy demographics with a set of continuity equations

invoking two **quenching mechanisms**

Results

1. Write the "passive" **Schechter parameters** in terms of the active population.
2. Derive the **time evolution** of $\phi_*(\mathbf{z})$.

Conclusions

Reduce parameter space for simulations
Passive galaxies described by double Schechter function
Satellite-quenched galaxies subset of the active population

Exact analytical time dependence of the amplitude
of the active galaxies

Validation against Weigel et al. 2016 best-fit for SDSS DR7
$f_\rho \sim 50\,\%$ in agreement with literature values

Implemented in the SkyPy galaxy module

Implemented in the SkyPy example page

Sonification with Strauss

-0:05

Questions

II. and the SkyPy project

7. Configuration Files

6. Simulation pipelines

5. Research & Development

4. The Library

3. Community Package

2. Members

1. Vision

1. The vision

- Observational cosmology limited by data access
- Open-data revolution in astronomy
- Challenge: access to sophisticated analysis **methods**.
- Emerging methods: forward modelling & machine learning.

- III generation of catalog production (**user-generated outputs**)
- **Open-source** off-project high-quality **Python** package
- **End-to-end simulations** of the astrophysical sky
- Interface with external software
- Enable **Forward Modelling** and **Machine Learning**

- Not a single pipeline simulation
- Do not replicate existing code

- **Reuse**
  - Astropy-affiliated packages
  - High-quality codes
- **Ecosystem** of compatible software

2. Members

Sarah Bridle
Richard Rollins
Juan Pablo Cordero
Nicolas Tessore
Ian Harrison
Laura Wolz

Adam Amara
Coleman Krawczyk
Lucia F. de la Bella
Ian Harry
Philipp Sudek
Laura Nutall
Ginevra Favole
Arthur Tolley
Andrew Lundgren
Andrew Williamson

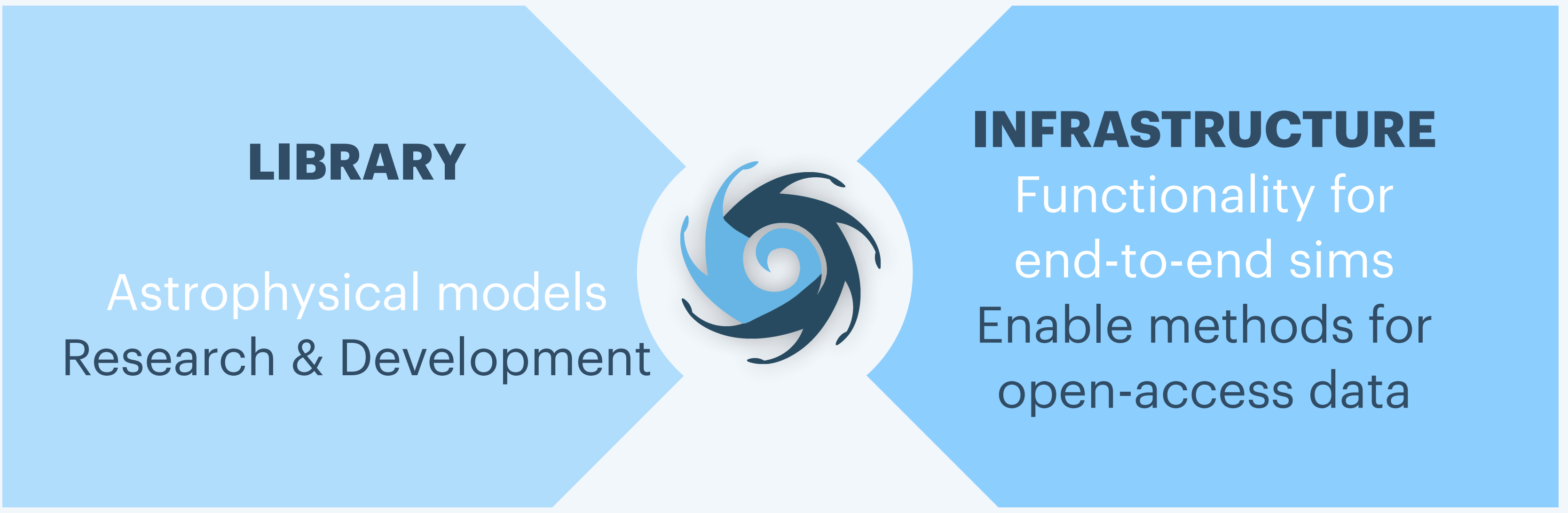
Brian Nord
Simon Birrer

Keiichi Umetsu
Sut-ieng Tam
William Hartley

https://skypyproject.org

3. Community Package

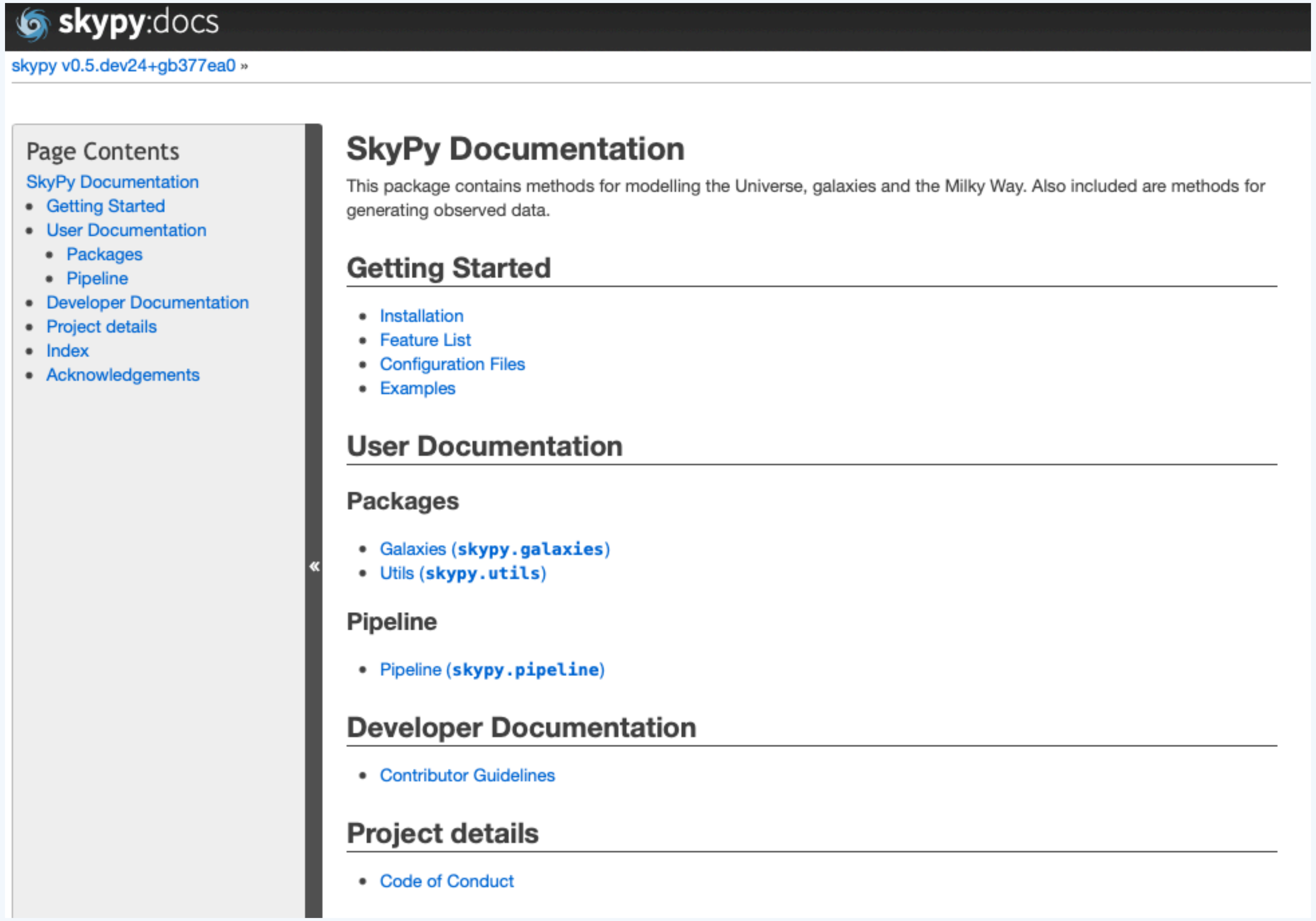
https://github.com/skypyproject/skypy.git



- **GitHub** organisation
- Unit tests & high-quality documentation
- Code review & Infrastructure team

```
my-pc: ~$ pip install skypy or
my-pc: ~$ conda install -c conda-forge skypy or
my-pc: ~$ git clone https://github.com/skypyproject/skypy.git

my-pc: ~$ ipython
…
[1]: import skypy
```



skypy:docs

skypy v0.5.dev24+gb377ea0 »

Page Contents

- SkyPy Documentation
- Getting Started
- User Documentation
  - Packages
  - Pipeline
- Developer Documentation
- Project details
- Index
- Acknowledgements

SkyPy Documentation

This package contains methods for modelling the Universe, galaxies and the Milky Way. Also included are methods for generating observed data.

Getting Started

- Installation
- Feature List
- Configuration Files
- Examples

User Documentation

Packages

- Galaxies (`skypy.galaxies`)
- Utils (`skypy.utils`)

Pipeline

- Pipeline (`skypy.pipeline`)

Developer Documentation

- Contributor Guidelines

Project details

- Code of Conduct

https://skypy.readthedocs.io/en/latest

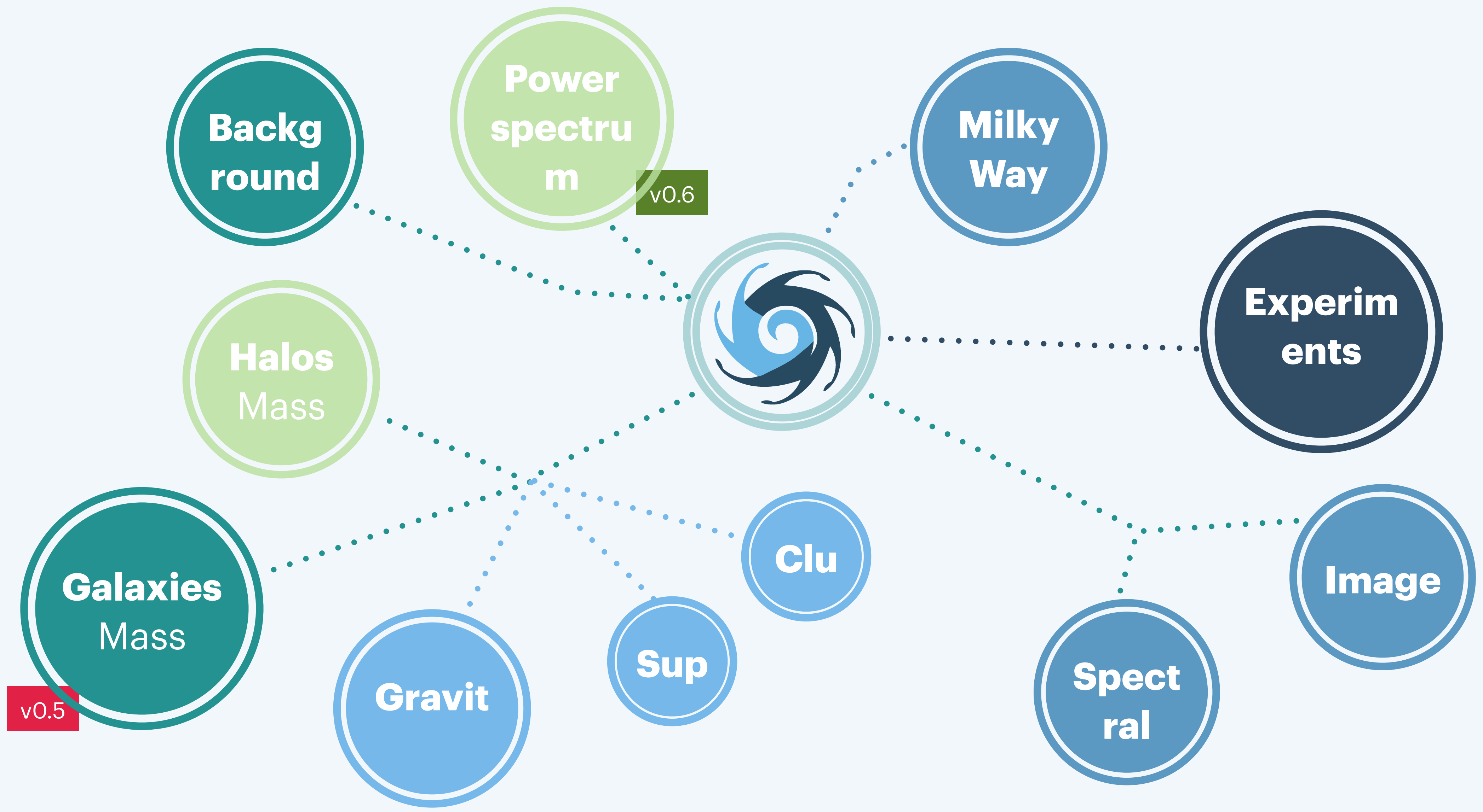
4. The Library

LIBRARY INFRASTRUCT

5. Research & Development

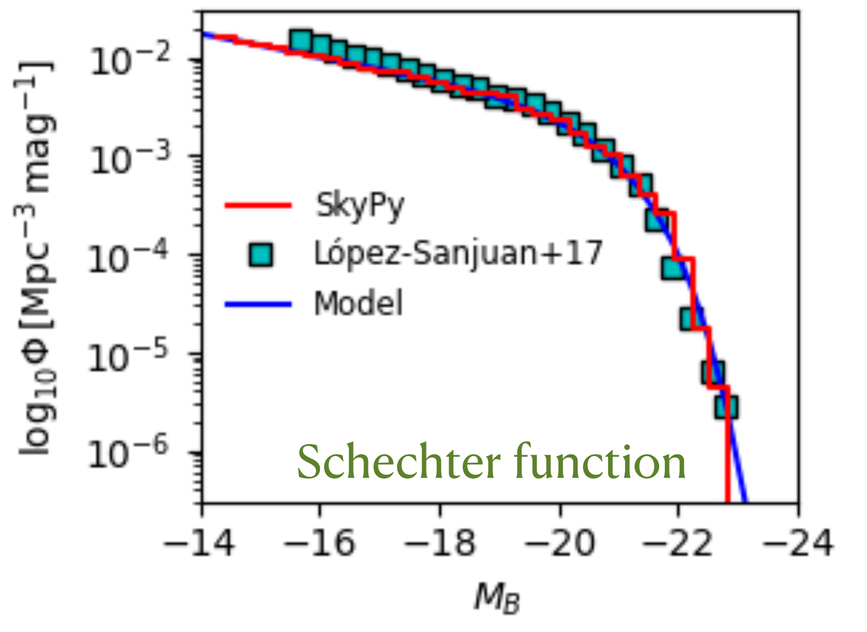
SkyPy **v0.5**

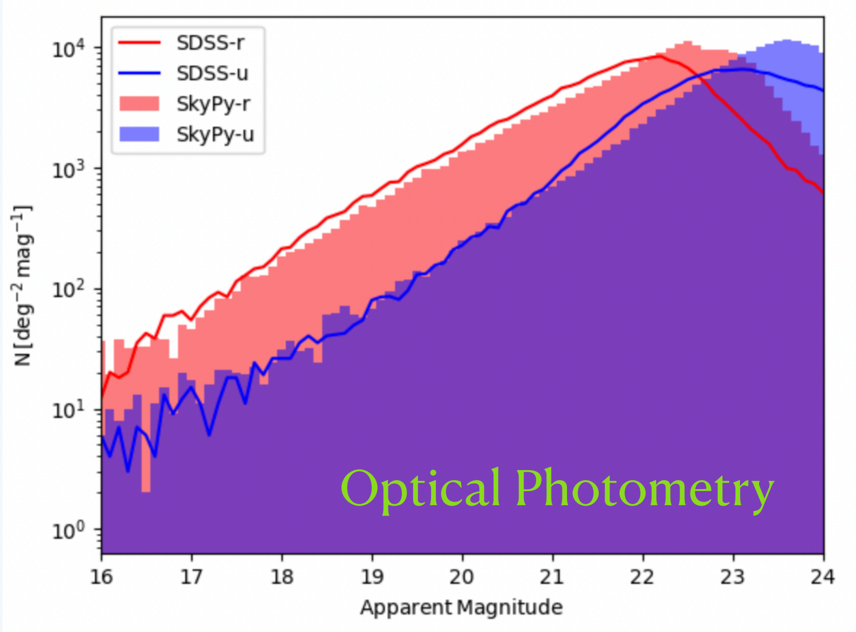
- **Luminosity Distributions** — Schechter Luminosity function
- **Morphological Distributions** — angular size, (early- and late-type) linear lognormal size distribution, beta ellipticity and Ryden 2004 ellipticity distributions.
- **Redshift Distributions** — redshifts from co-moving density, Schechter (luminosity and stellar mass) redshift distribution, Smail+94 redshift distribution.
- **Spectral Energy Distribution Modelling** — Dirichlet coefficients, Correct templates.
- **Stellar Mass Distribution** — Schechter stellar mass function.

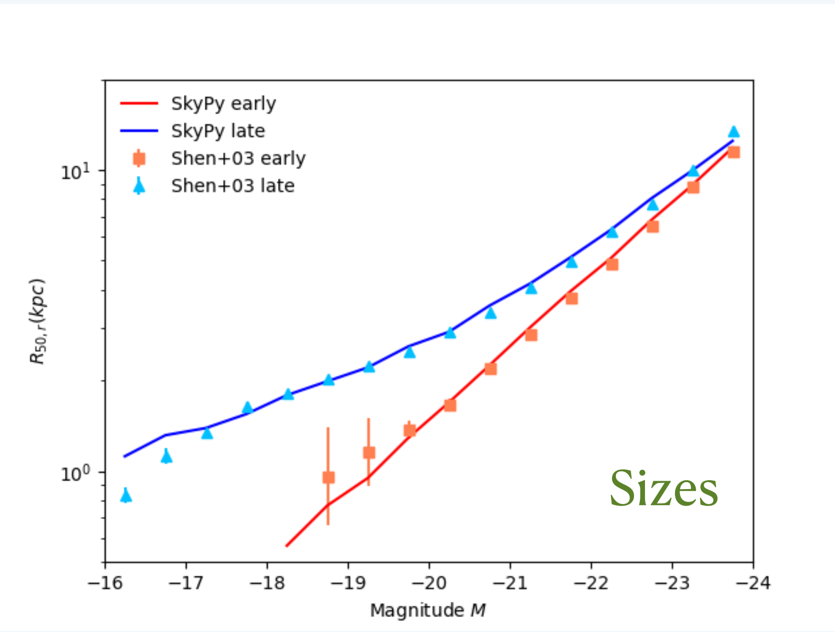


SkyPy **v0.6**

- **Power Spectrum** — CAMB, Halofit, CLASS, Eisenstein & Hu, growth functions
- **Dark Matter Halos** — Colossus, halo and sub-halo mass sampler, ellipsoidal and spherical collapse functions (Press-Schechter, Sheth-Tormen), abundance matching, quenching models





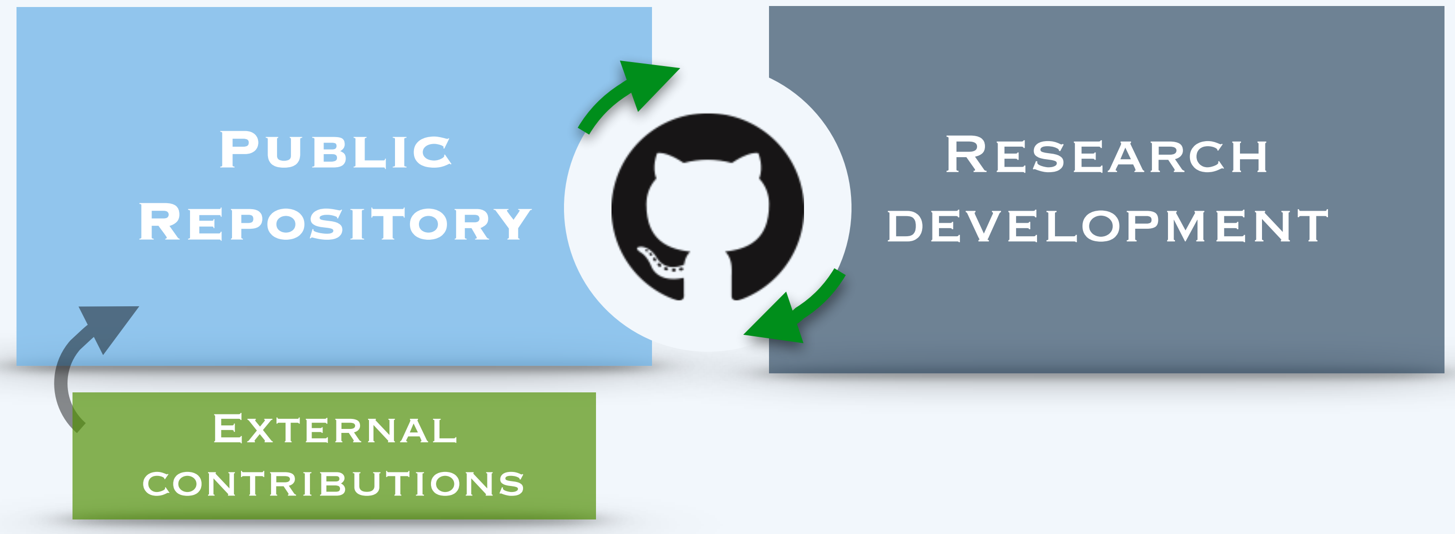


https://skypy.readthedocs.io/en/stable

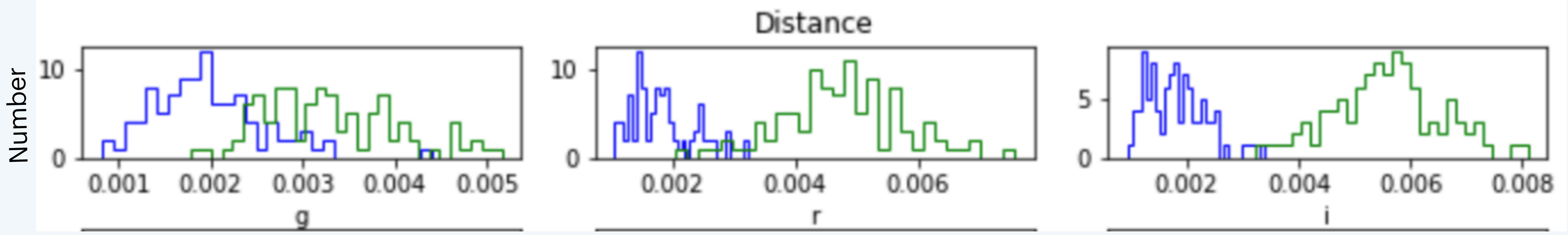
https://github.com/skypyproject/skypy.git

5. Research & Development

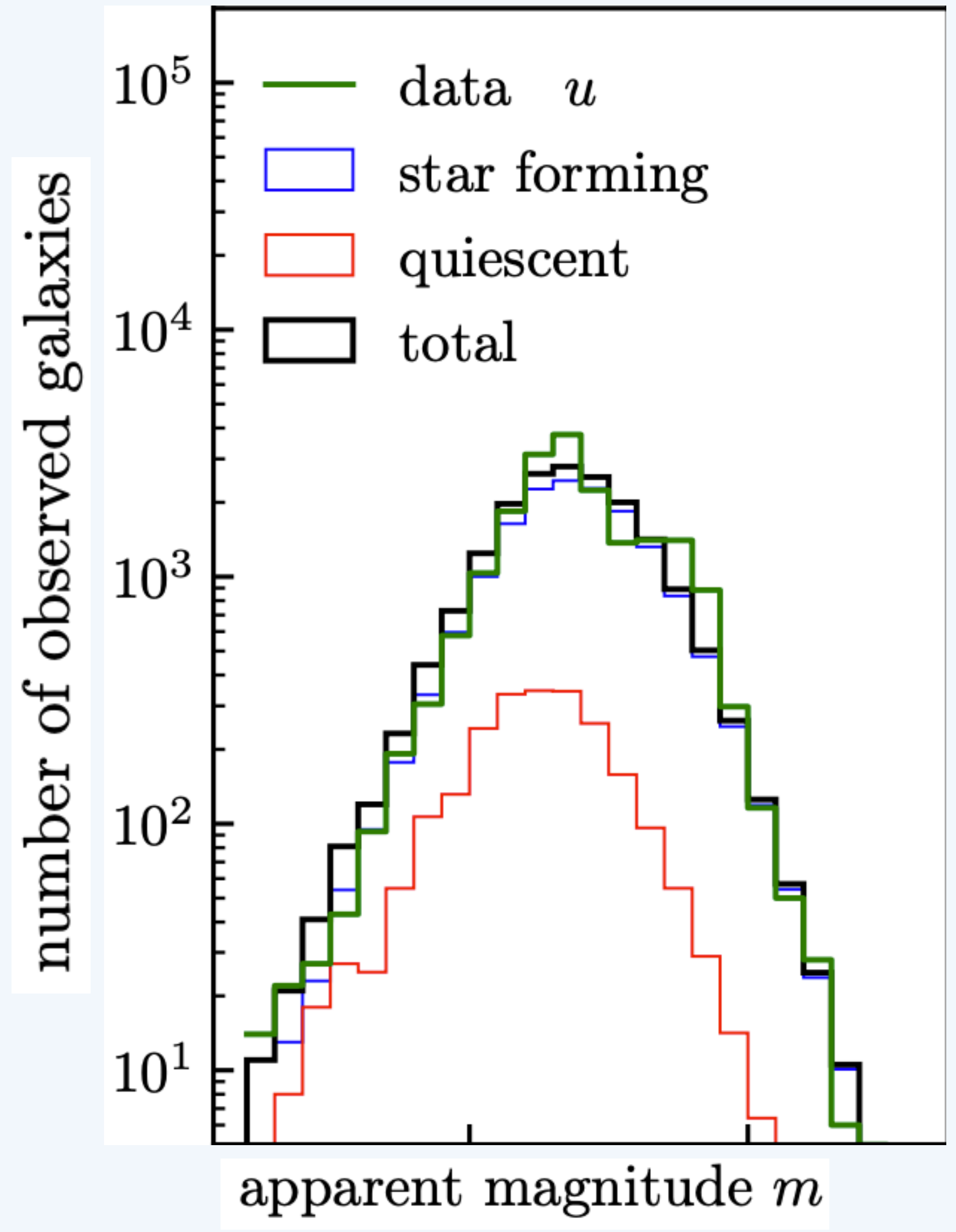
Key **SkyPy** is driven by science projects



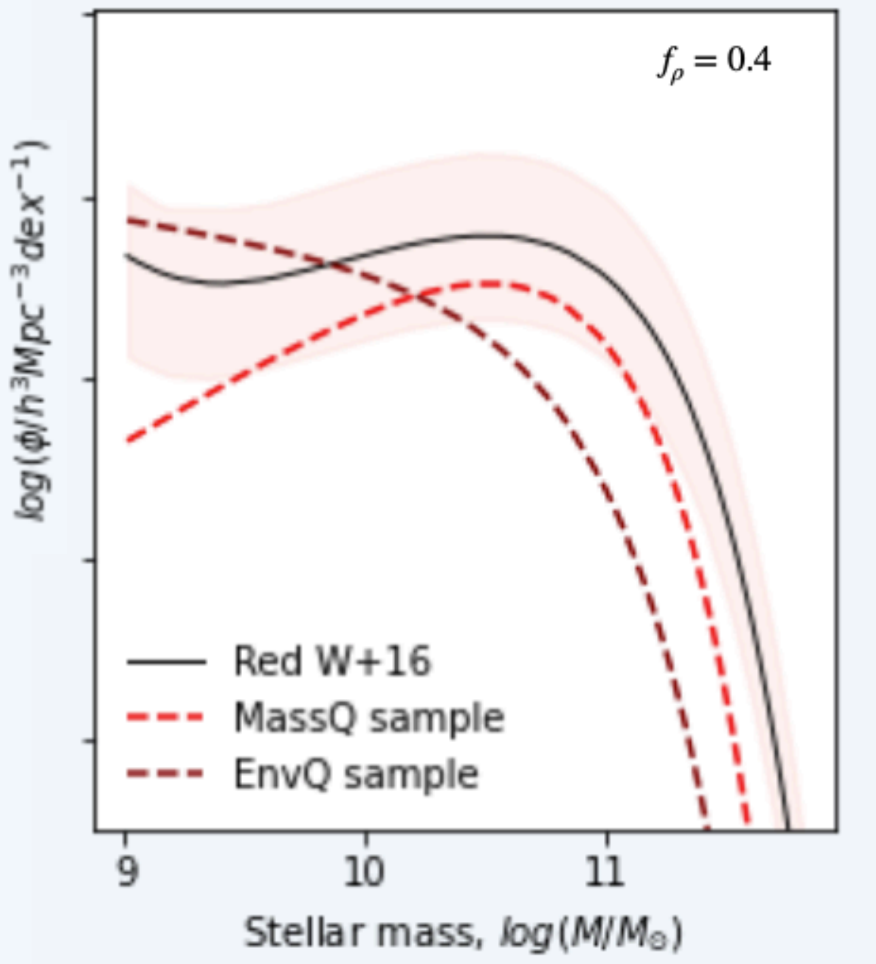
- ***Likelihood-Free Inference for Cluster Weak Lensing*** - Sut-Ieng Tam, ASIAA
- ***Projected Galaxy Ellipticities*** - Juan Pablo Cordero, Univ. of Manchester
- ***Galaxy Demographics*** - Lucia F. de la Bella, Univ. of Portsmouth
- ***Forecasting Optical Galaxy Surveys***- Philipp Sudek, Univ. of Portsmouth
- ***Galaxies*** - William Hartley
- ***Gravitational Wave Binary Merger Populations*** - Arthur Tolley, Univ. of Portsmouth



Investigation of Schechter parameter sensitivity of a DES-like survey (Sudek+ in prep).
Big difference of the green and blue histogram indicates high constraining power using the corresponding observable



Apparent magnitude distribution in the SDSS u filter simulated with SkyPy (blue, red, black) compared to SDSS data (Tessore+ in prep.)



Schechter function in the quenching model vs SDSS best fit (de la Bella + in prep.)

6. Simulation pipelines

Key
- YAML-based config files
- The **SkyPy Driver** runs end-to-end **pipelines**
- **Total flexibility**!

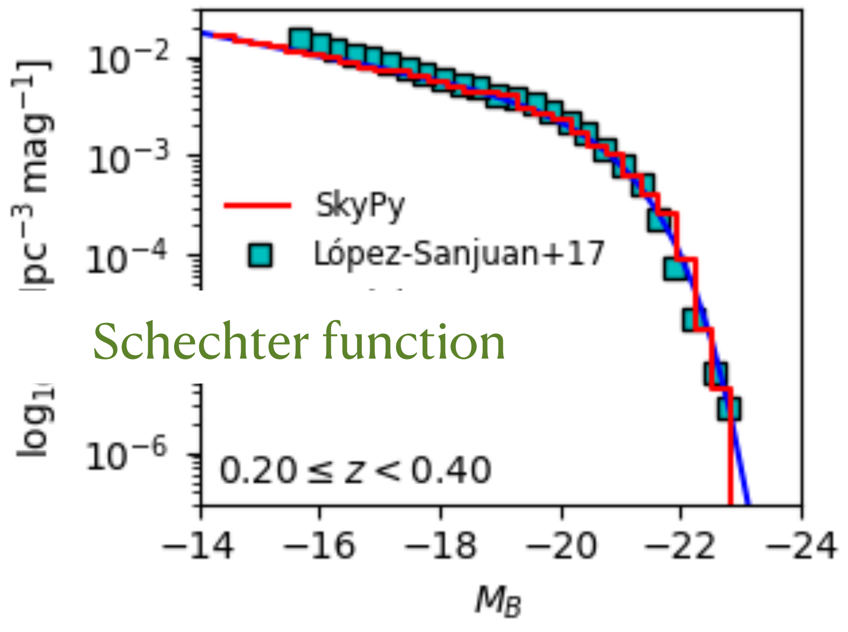
- SkyPy Pipeline
- **KEY: you** can write your own **pipelines!**

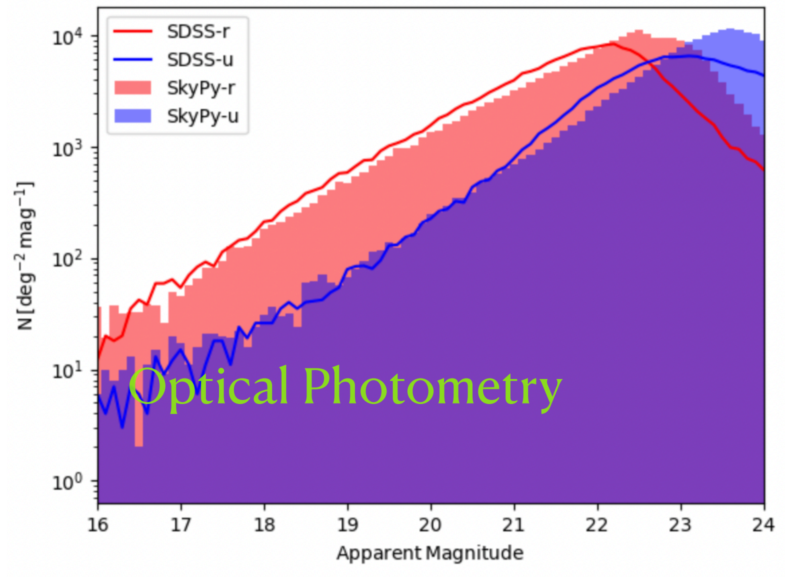
Combine SkyPy with your favourite software!

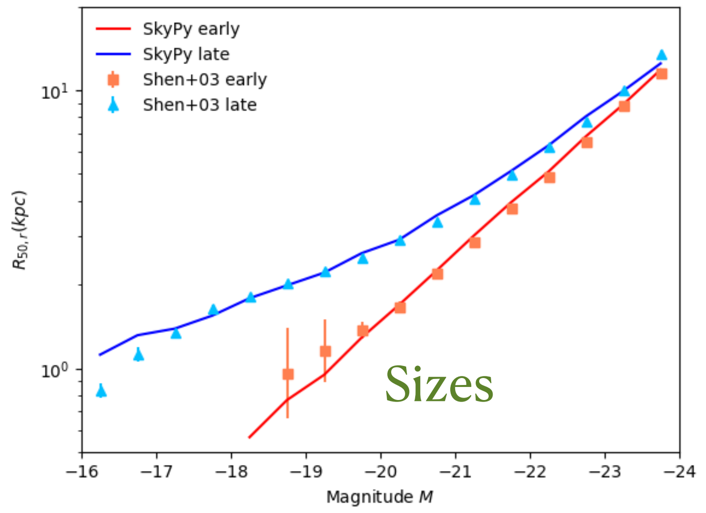
Simulated lensed galaxies using *SkyPy* and *lenstronomy* (Simon Birrer)

LIBRARY INFRASTRUCT

SkyPy PIPELINES







7. Configuration files

SkyPy Syntax

- **Variables** — Astropy quantities, import objects
- **Parameters** — variables modified at execution
- **Functions** — cosmology, job completion
- **Tables** — multicolumn assignment, table reference

Example: luminosity.yml

```yaml
cosmology: !astropy.cosmology.default_cosmology.get []
z_range: !numpy.linspace [0, 2, 21]
M_star: !astropy.modeling.models.Linear1D [-0.9, -20.4]
phi_star: !astropy.modeling.models.Exponential1D [3e-3, -9.7]
magnitude_limit: 23
sky_area: 0.1 deg2
tables:
  blue_galaxies:
    redshift, magnitude: !skypy.galaxies.schechter_lf
      redshift: $z_range
      M_star: $M_star
      phi_star: $phi_star
      alpha: -1.3
      m_lim: $magnitude_limit
      sky_area: $sky_area
```

```python
import matplotlib.pyplot as plt
from skypy.pipeline import Pipeline

# Execute SkyPy luminosity pipeline
pipeline = Pipeline.read("luminosity.yml")
pipeline.execute()

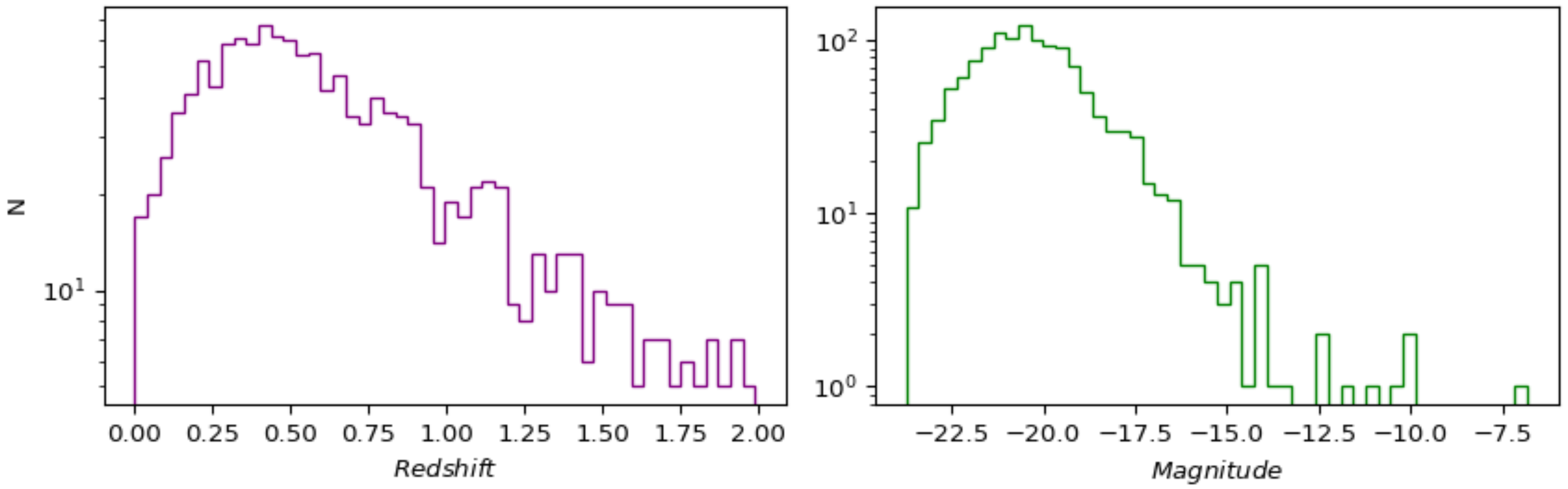
# Blue population
skypy_galaxies = pipeline['blue_galaxies']

# Plot histograms
fig, axs = plt.subplots(1, 2, figsize=(9, 3))

axs[0].hist(skypy_galaxies['redshift'], bins=50, histtype='step', color='purple')
axs[0].set_xlabel(r'$Redshift$')
axs[0].set_ylabel(r'$\mathrm{N}$')
axs[0].set_yscale('log')

axs[1].hist(skypy_galaxies['magnitude'], bins=50, histtype='step', color='green')
axs[1].set_xlabel(r'$Magnitude$')
axs[1].set_yscale('log')

plt.tight_layout()
plt.show()
```



You can also run the pipeline directly from the command line and write the outputs to a fits file:

```
$ skypy luminosity.yml luminosity.fits
```

https://skypy.readthedocs.io/en/latest/configuration_files.html

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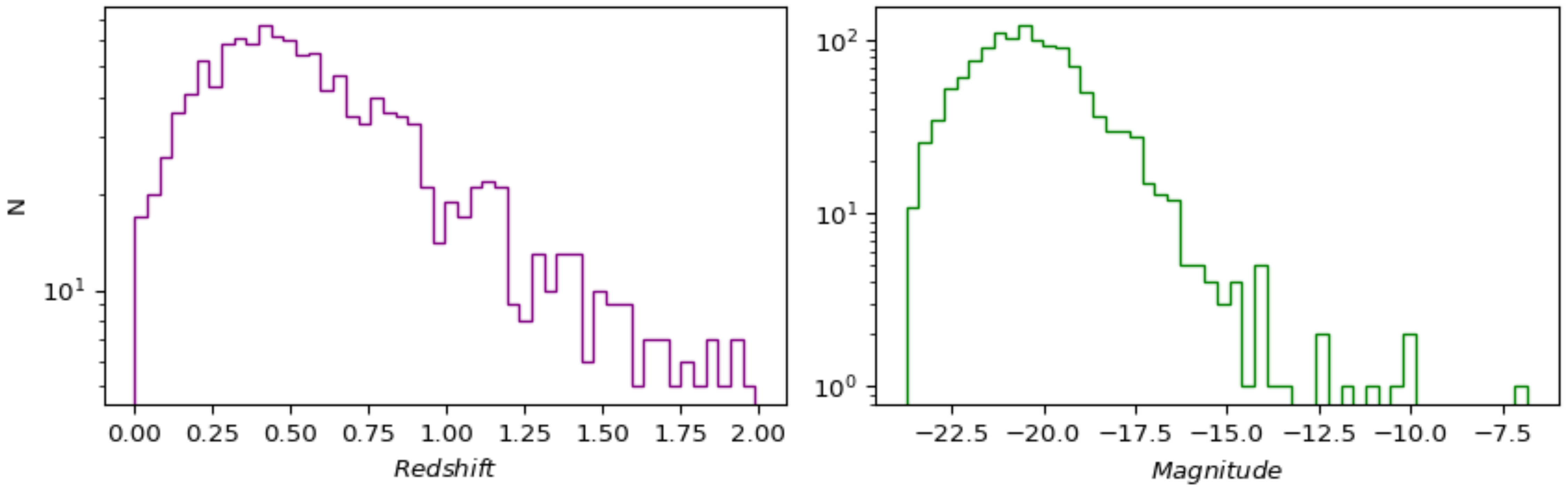

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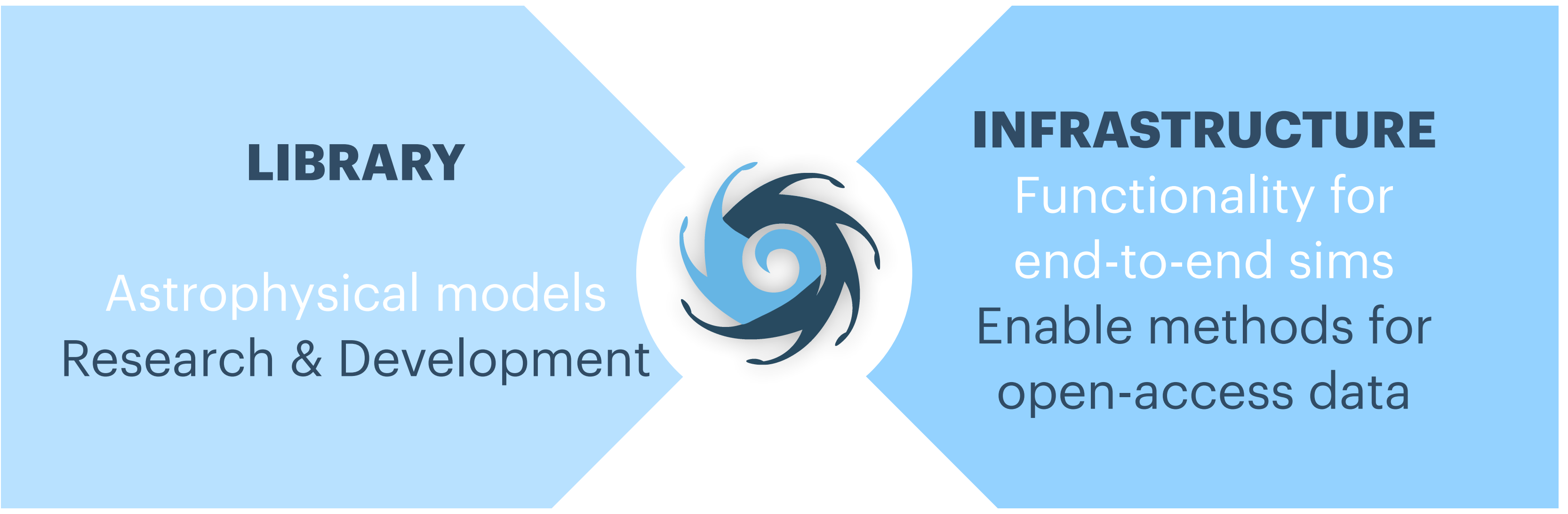
```

Summary

COMMUNITY PACKAGE

- **Open-source** off-project
- High-quality **Python** package



- **GitHub** organisation
- Unit tests & high-quality documentation
- Code review & Infrastructure team

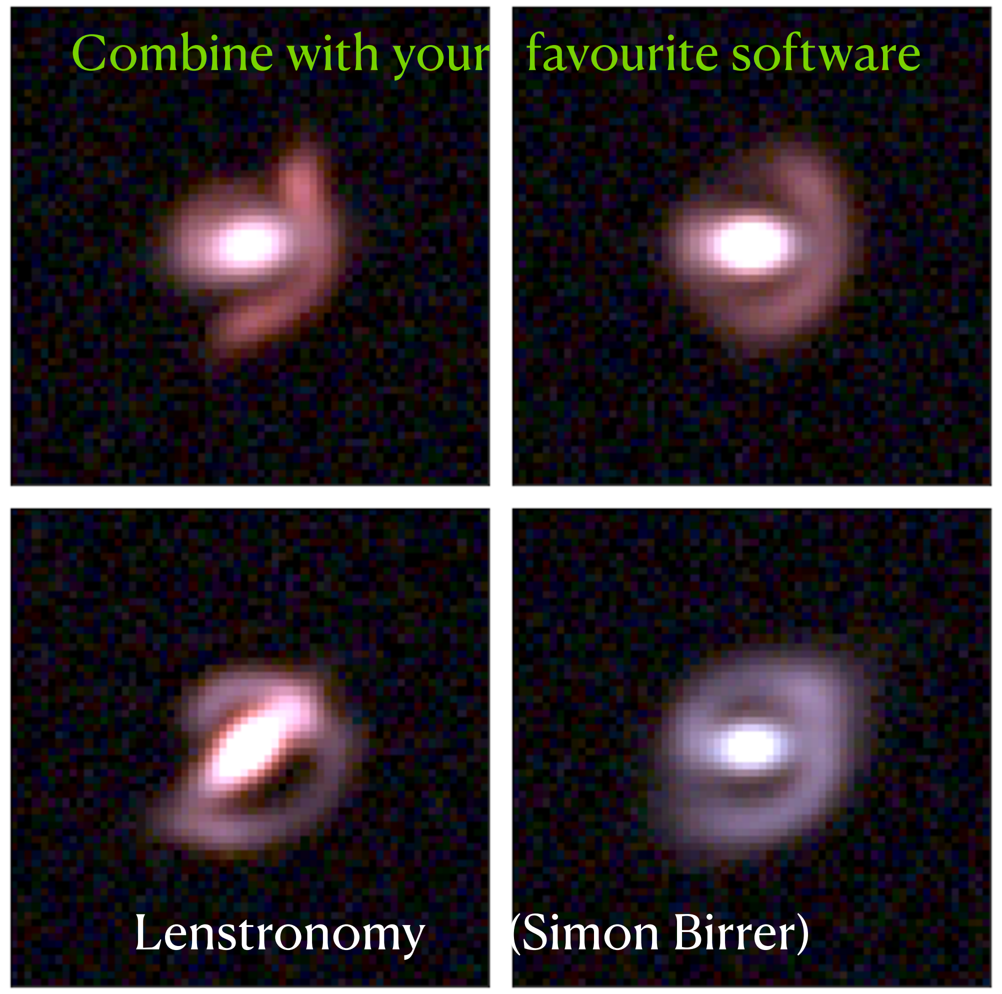
News

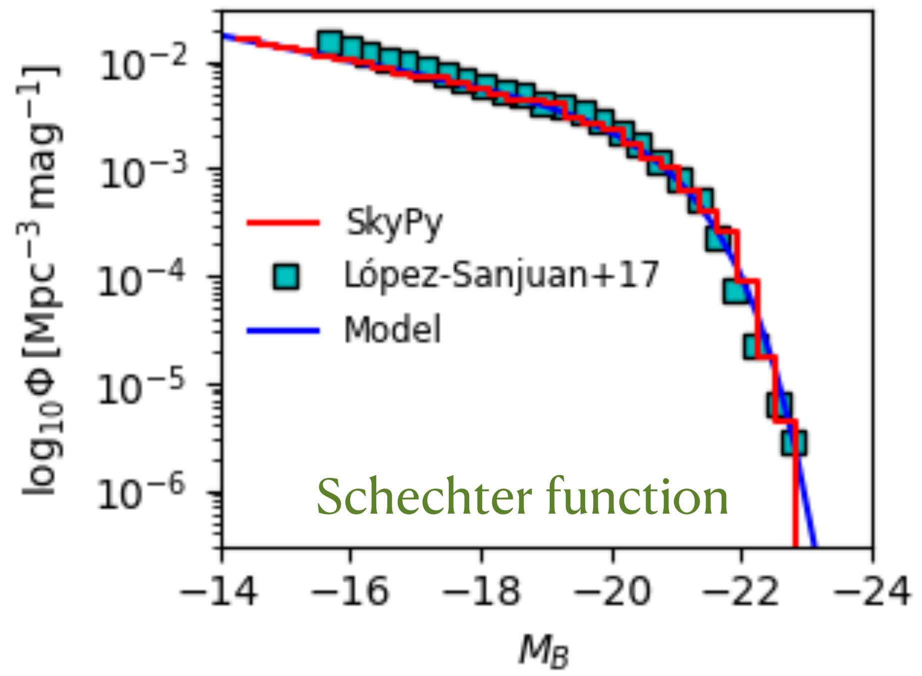
- **v0.6** release: halo & power spectrum.
- Journal of Open-Source Software

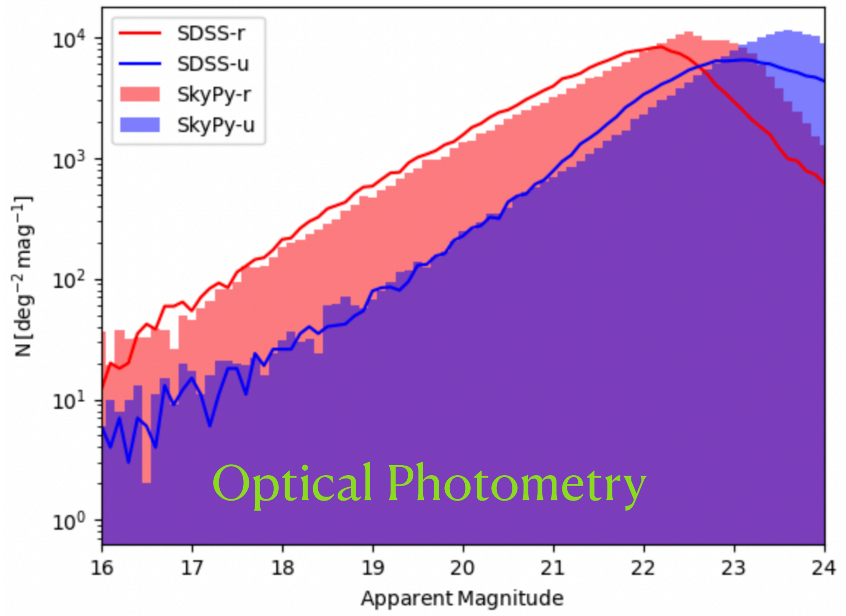
SIMULATION PIPELINES

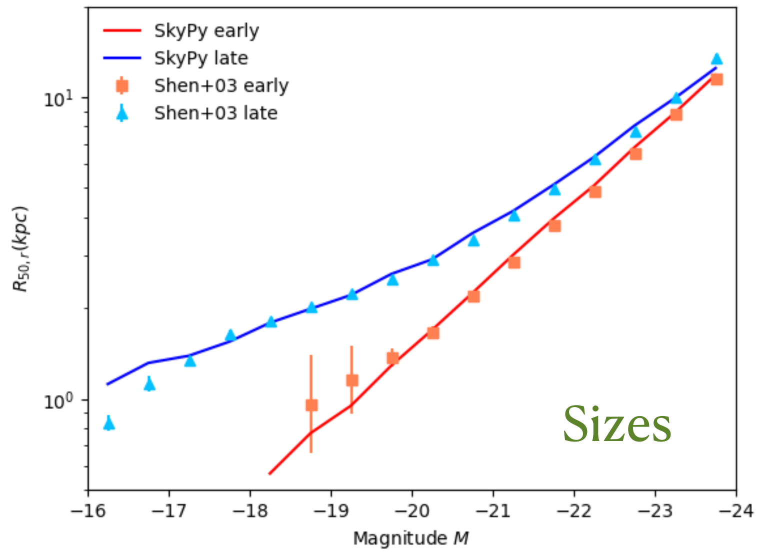
- YAML-based config files
- The **SkyPy Driver** runs end-to-end **pipelines**
- **Total flexibility**!

- SkyPy Pipeline
- **KEY: you** can write your own **pipelines!**









https://github.com/skypyproject/skypy.git

https://skypyproject.org

https://skypy.readthedocs.io/en/latest/examples/index.html

Open your terminal...

```
my-pc: -$ pip install skypy or
my-pc: -$ conda install -c conda-forge skypy or
my-pc: -$ git clone https://github.com/skypyproject/skypy.git

my-pc: -$ ipython
…
[1]: import skypy
```

Questions?