



anr[©] | SCInf



Realistic simulations for precision cosmology with Type Ia Supernovae

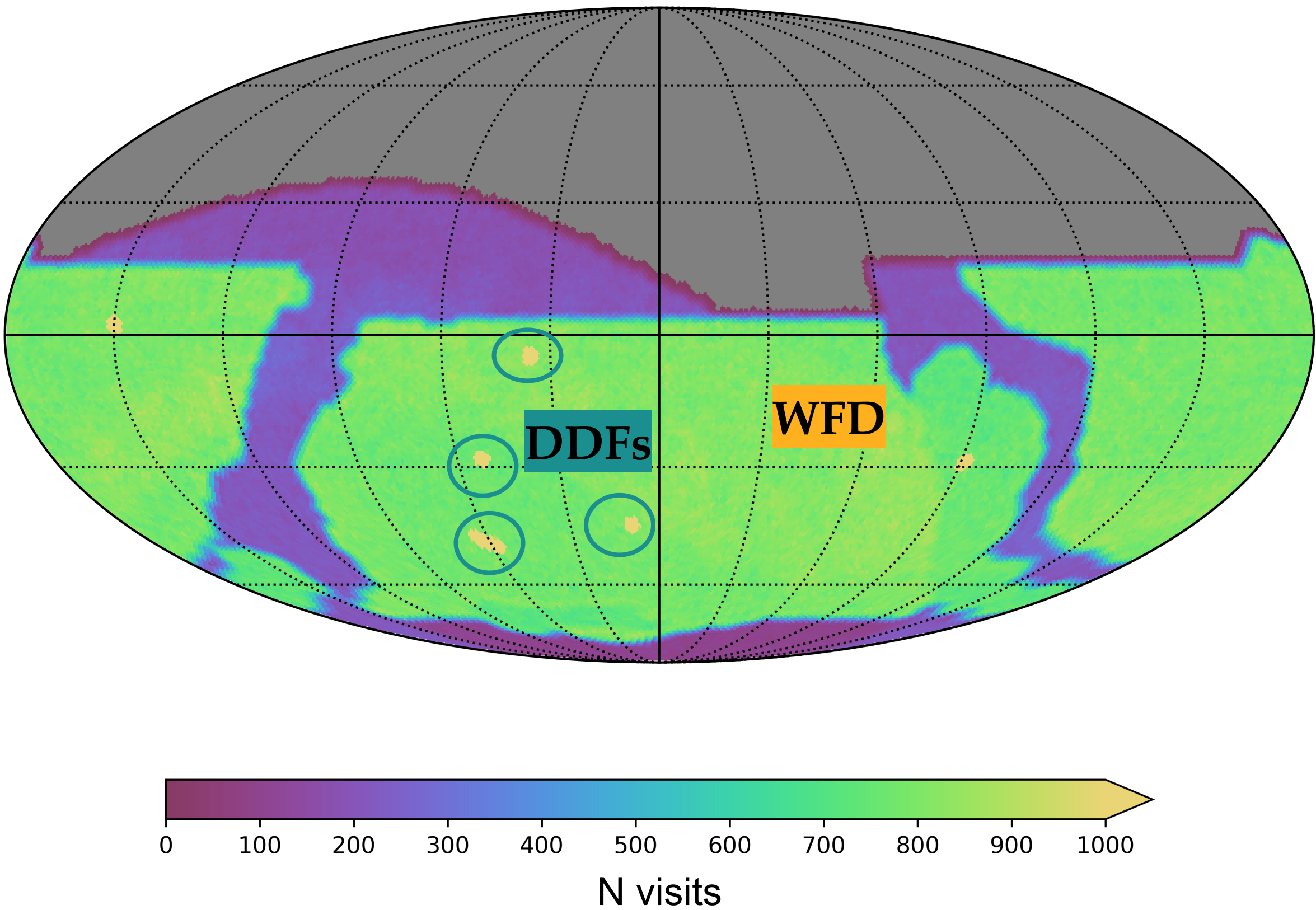
Luna Dellazzeri

1st year PhD student, under the supervision of Mickaël Rigault and Florian Ruppin

LSST for SN Ia

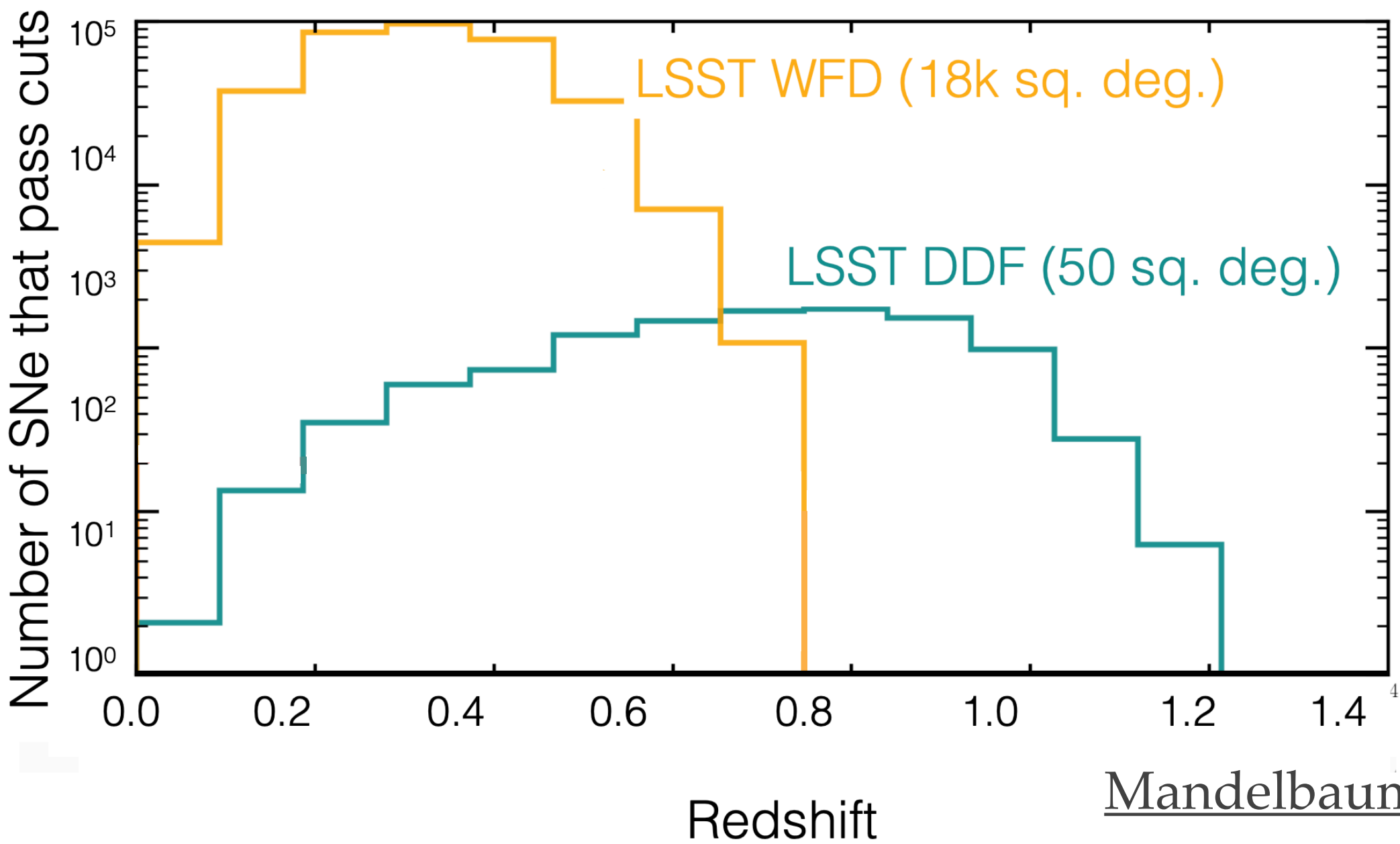
Legacy Survey of Space and Time

baseline_v5.0.0_10yrs all bands: NVisits



survey-strategy.lsst.io

- 10-year survey of the southern sky, located at the Vera Rubin Observatory
- Observing strategy optimized for transient cosmology :
 - ❖ **Wide Fast Deep** (detection of large number of transients)
 - ❖ **Deep Drilling Fields** (detailed follow-up, high quality lightcurves, host galaxy redshift)
- Over 10 years : $> 10^5$ SN Ia observed



[Mandelbaum et al. 2019](#)

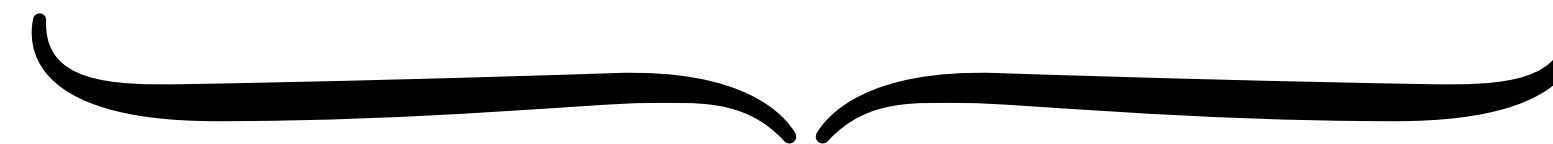
LSST DESC SNIa Cosmology Collab

Simulation pipeline

- *SNANA*: Kessler, Vincenzi et al.
- *LightCurveLynx*: Dai et al.
- *skysurvey*: Rigault, Ginolin, Dellazzeri et al.

Inference pipeline (validation teams)

- *FlowSN*: Boyd, Mandel et al.
- *CIGaRS*: Karchev, Giunta, Trotta et al.
- *Unity*: Rubin et al.
- *BBC*: Kessler et al.
- *Scinf*: Rigault, Triguí et al.



SNIa cosmology pipeline

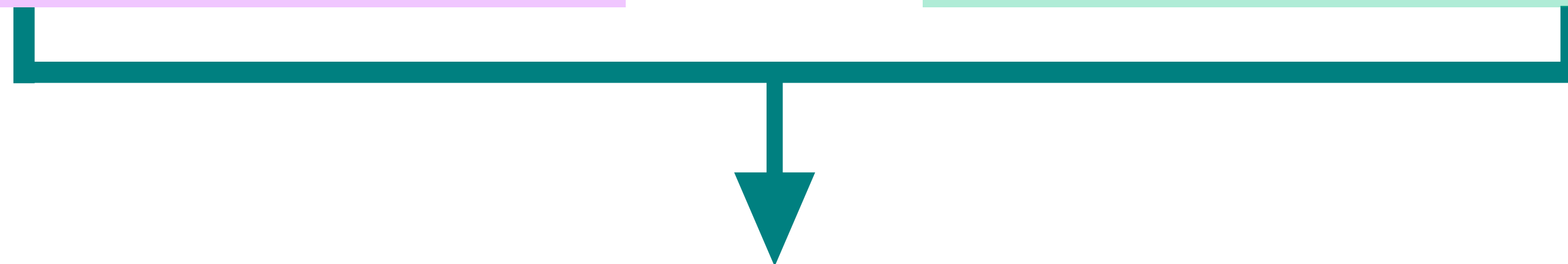
LSST DESC SNIa Cosmology Collab

Simulation pipeline

- *SNANA*: Kessler, Vincenzi et al.
- *LightCurveLynx*: Dai et al.
- *skysurvey*: Rigault, Ginolin, Dellazzeri et al.

Inference pipeline (validation teams)

- *FlowSN*: Boyd, Mandel et al.
- *CIGaRS*: Karchev, Giunta, Trotta et al.
- *Unity*: Rubin et al.
- *BBC*: Kessler et al.
- *Scinf*: Rigault, Trigui et al.



Data challenges

Milestone 1 (ongoing): compare and validate the 3 simulator's outputs for the simplest simulations

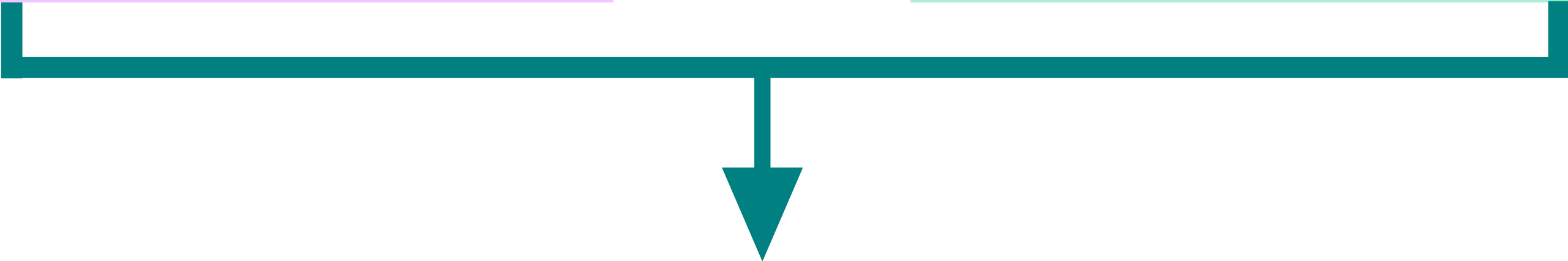
LSST DESC SNIa Cosmology Collab

Simulation pipeline

- *SNANA*: Kessler, Vincenzi et al.
- *LightCurveLynx*: Dai et al.
- *skysurvey*: Rigault, Ginolin, Dellazzeri et al.

Inference pipeline (validation teams)

- *FlowSN*: Boyd, Mandel et al.
- *CIGaRS*: Karchev, Giunta, Trotta et al.
- *Unity*: Rubin et al.
- *BBC*: Kessler et al.
- *Scinf*: Rigault, Trigui et al.



Data challenges

Milestone 1 (ongoing): compare and validate the 3 simulator's outputs for the simplest simulations

Milestone 2: add selection effects, host correlations



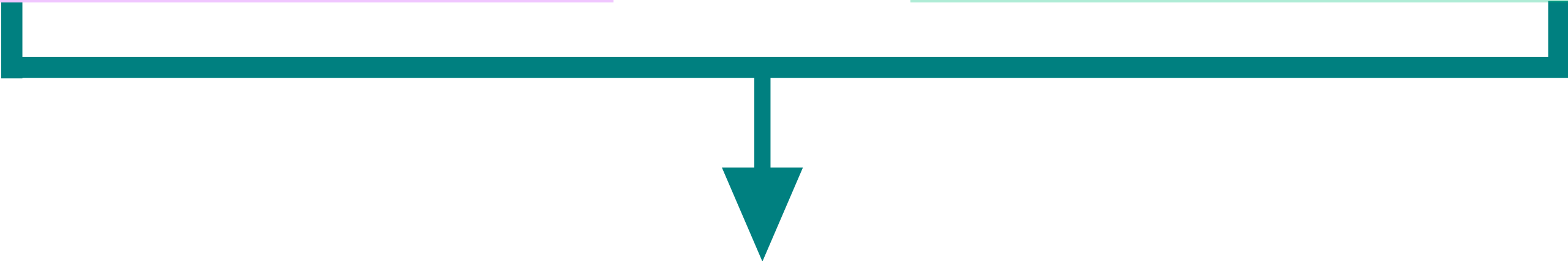
LSST DESC SNIa Cosmology Collab

Simulation pipeline

- *SNANA*: Kessler, Vincenzi et al.
- *LightCurveLynx*: Dai et al.
- *skysurvey*: Rigault, Ginolin, Dellazzeri et al.

Inference pipeline (validation teams)

- *FlowSN*: Boyd, Mandel et al.
- *CIGaRS*: Karchev, Giunta, Trotta et al.
- *Unity*: Rubin et al.
- *BBC*: Kessler et al.
- *Scinf*: Rigault, Trigui et al.



Data challenges

Milestone 1 (ongoing): compare and validate the 3 simulator's outputs for the simplest simulations

Milestone 2: add selection effects, host correlations

Milestone 3: add other astrophysical effects (contamination of non-Ia, ...), photometric calibration



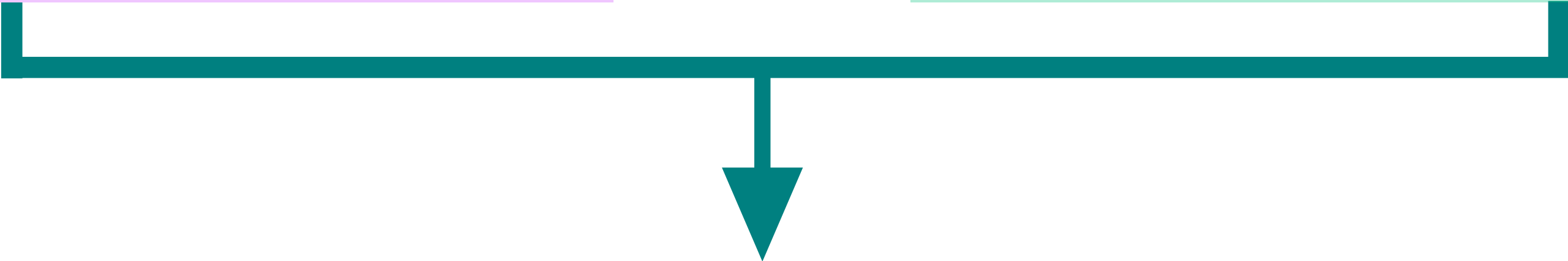
LSST DESC SNIa Cosmology Collab

Simulation pipeline

- *SNANA*: Kessler, Vincenzi et al.
- *LightCurveLynx*: Dai et al.
- *skysurvey*: Rigault, Ginolin, Dellazzeri et al.

Inference pipeline (validation teams)

- *FlowSN*: Boyd, Mandel et al.
- *CIGaRS*: Karchev, Giunta, Trotta et al.
- *Unity*: Rubin et al.
- *BBC*: Kessler et al.
- *Scinf*: Rigault, Trigui et al.



Data challenges

Milestone 1 (ongoing): compare and validate the 3 simulator's outputs for the simplest simulations

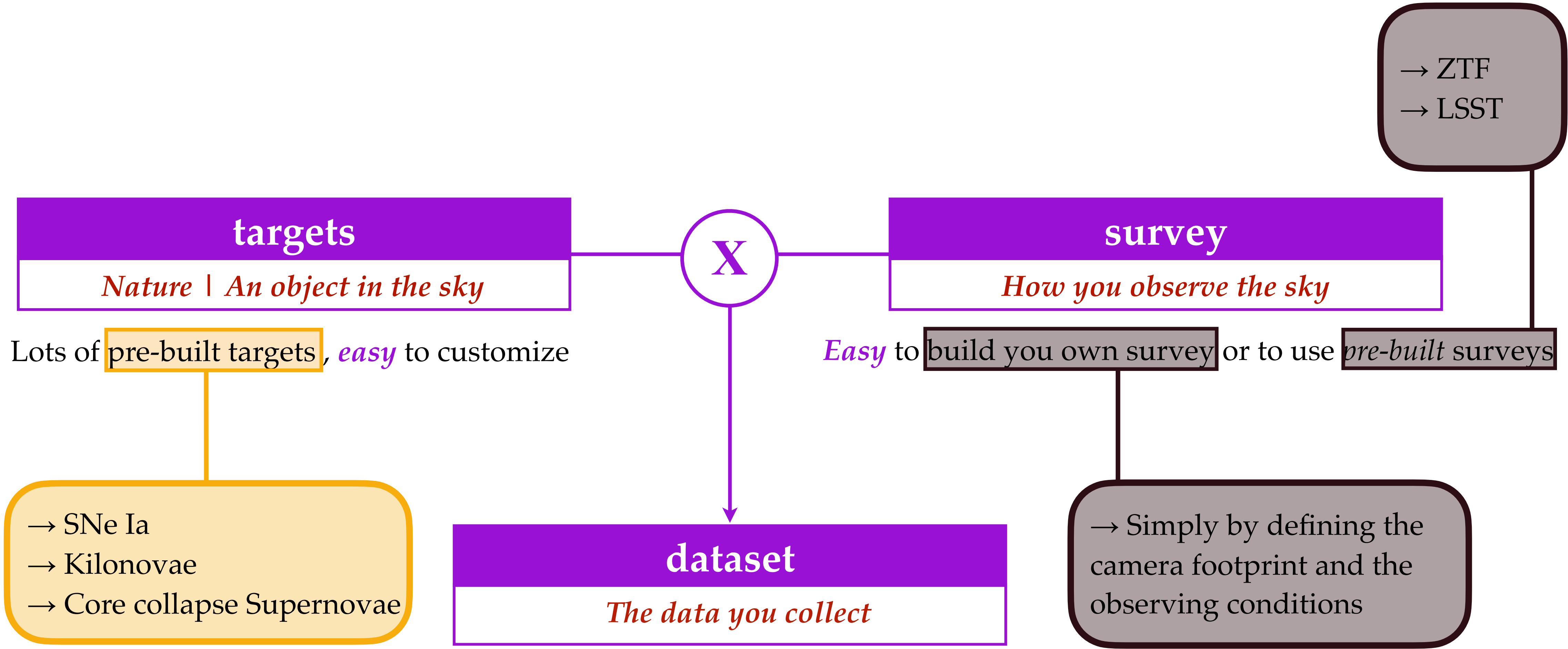
Milestone 2: add selection effects, host correlations

Milestone 3: add other astrophysical effects (contamination of non-Ia, ...), photometric calibration

Milestone 4: LSST realistic baseline model

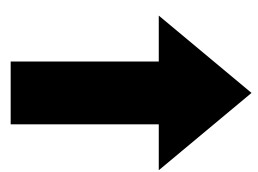
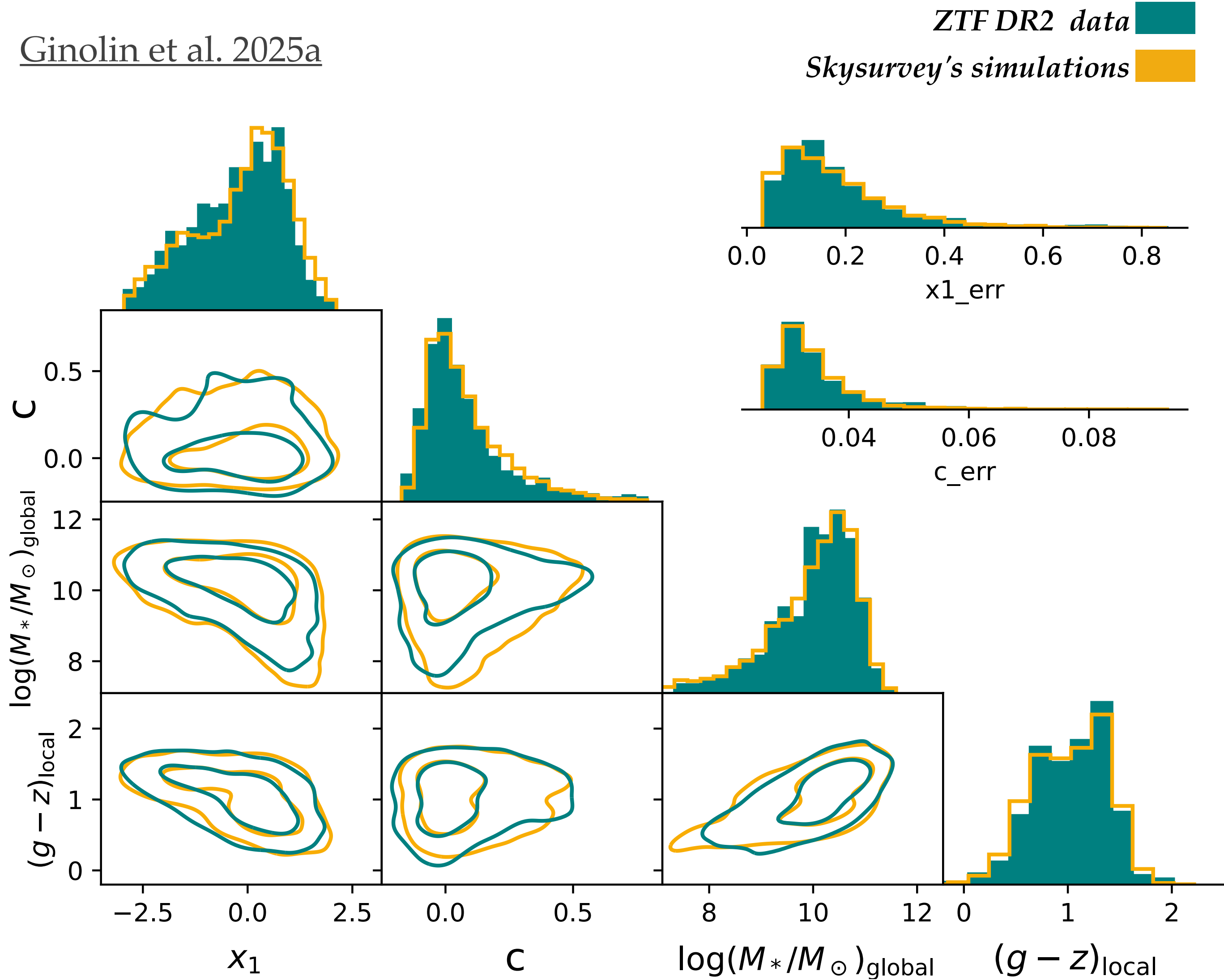


skysurvey : concept



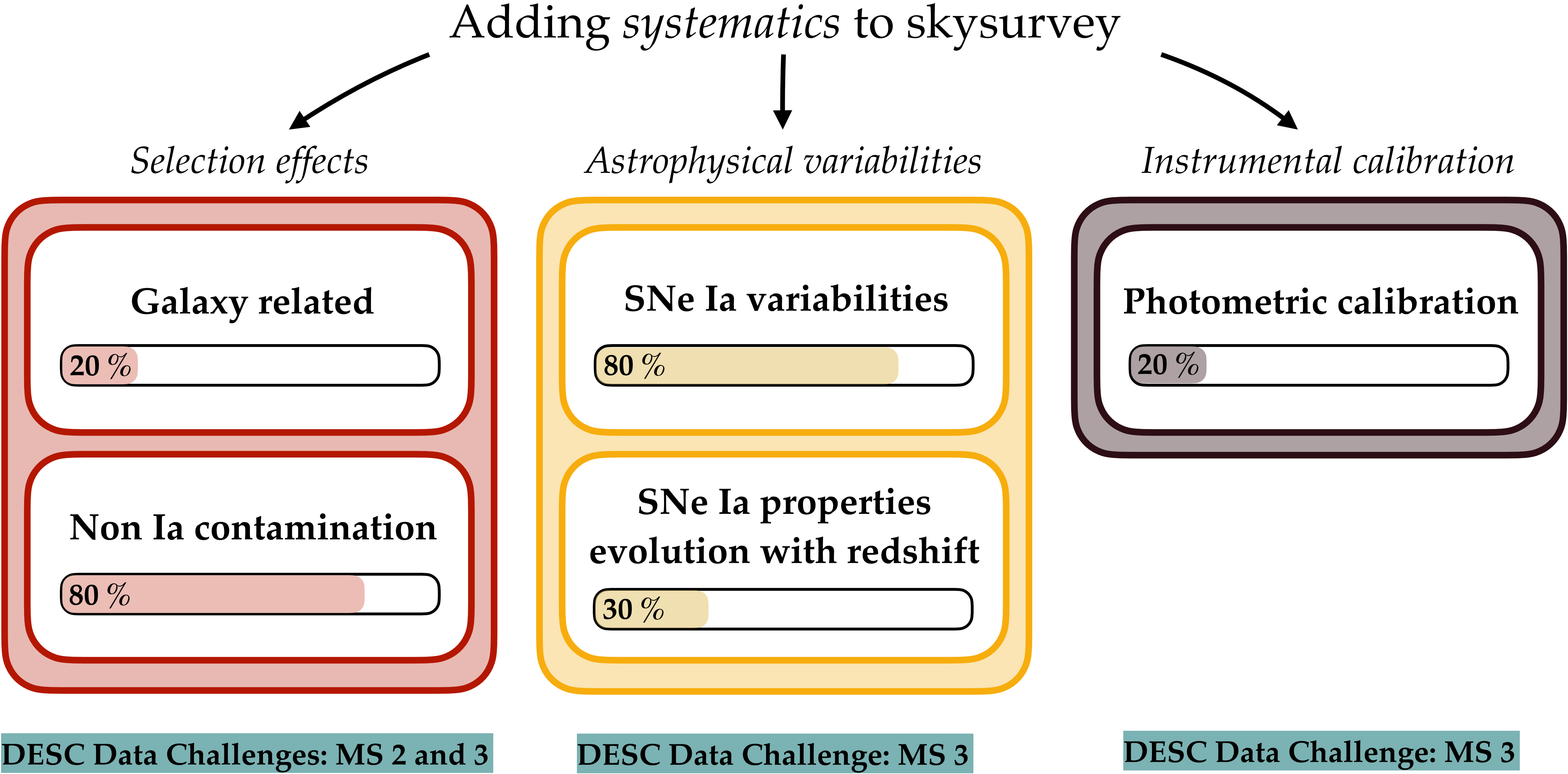
Current skysurvey simulations

Ginolin et al. 2025a



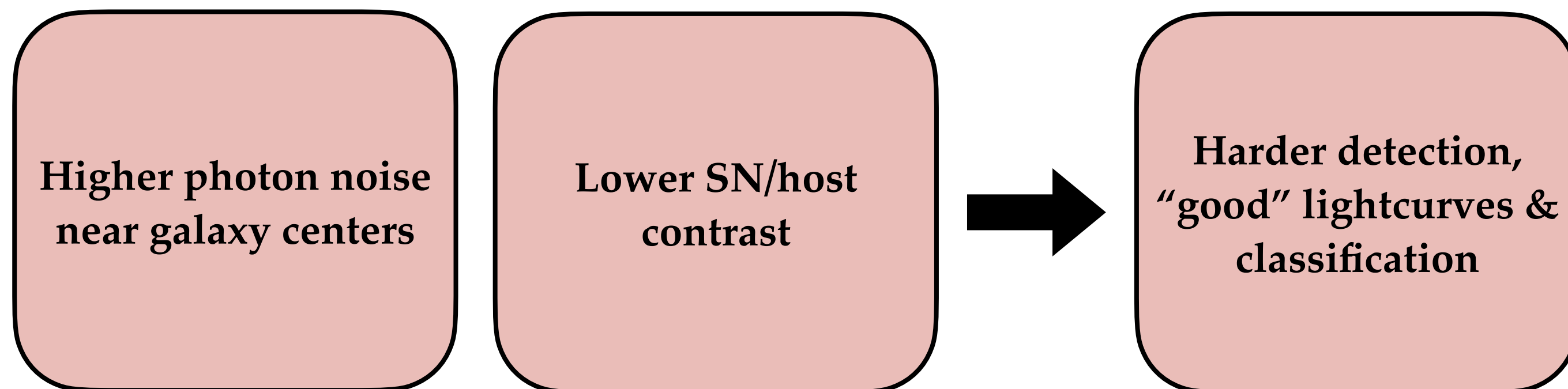
Current agreement between skysurvey simulations with ZTF DR2 SNe Ia data for simple DR2 selection effects

Towards realistic simulations

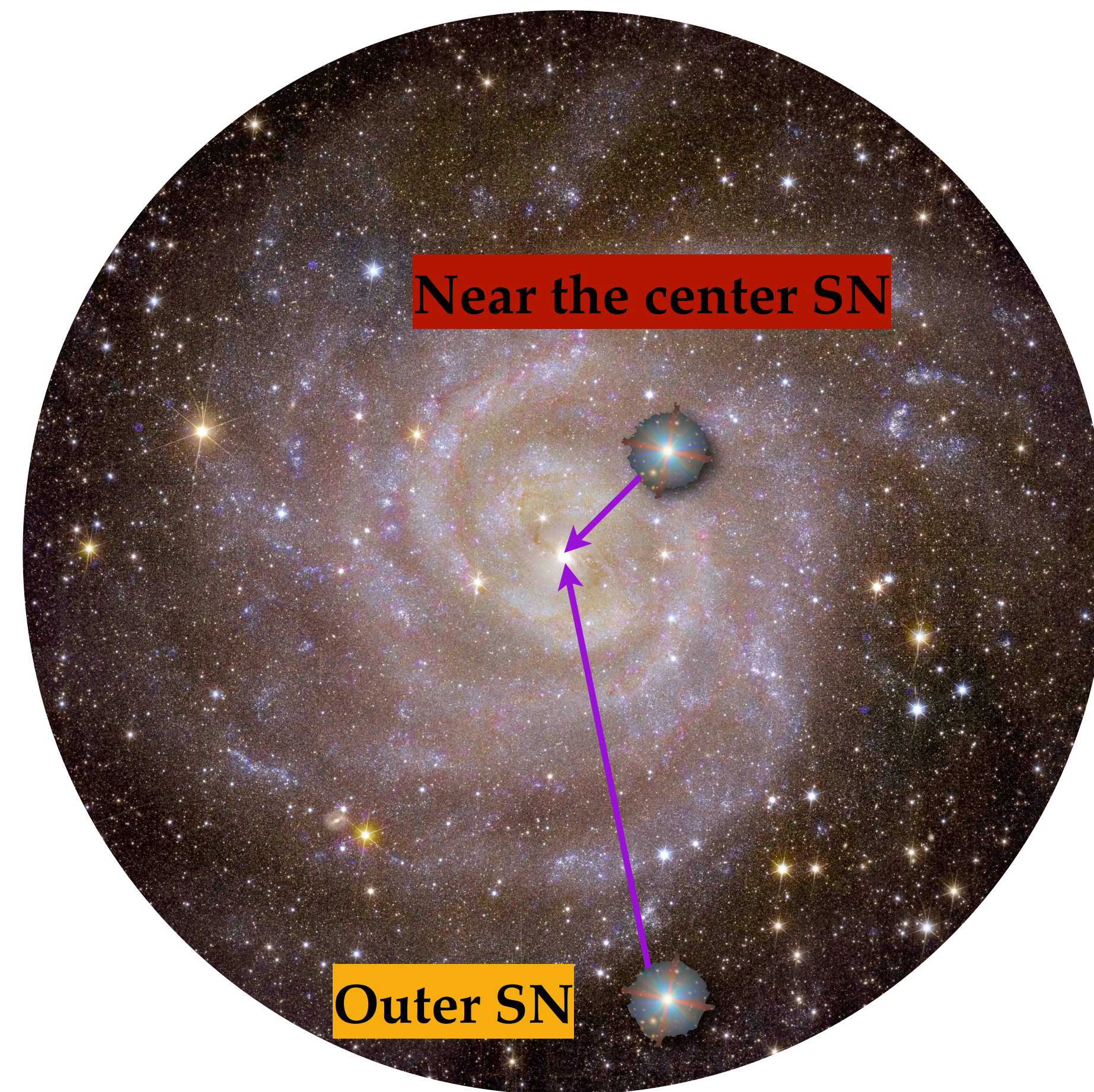
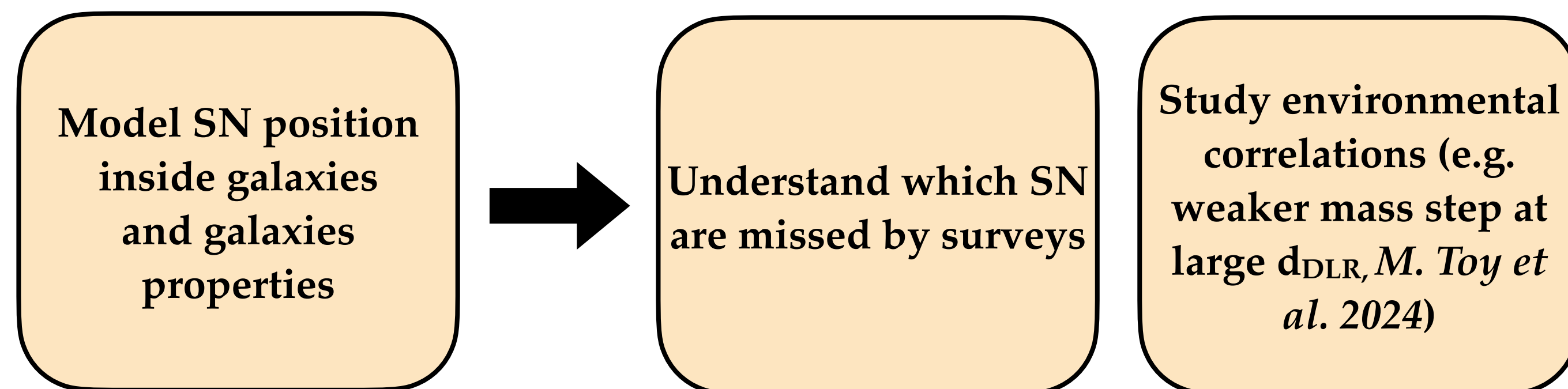


Galaxy selection effects

Host-dependent selection effects:



Implementation in skysurvey:



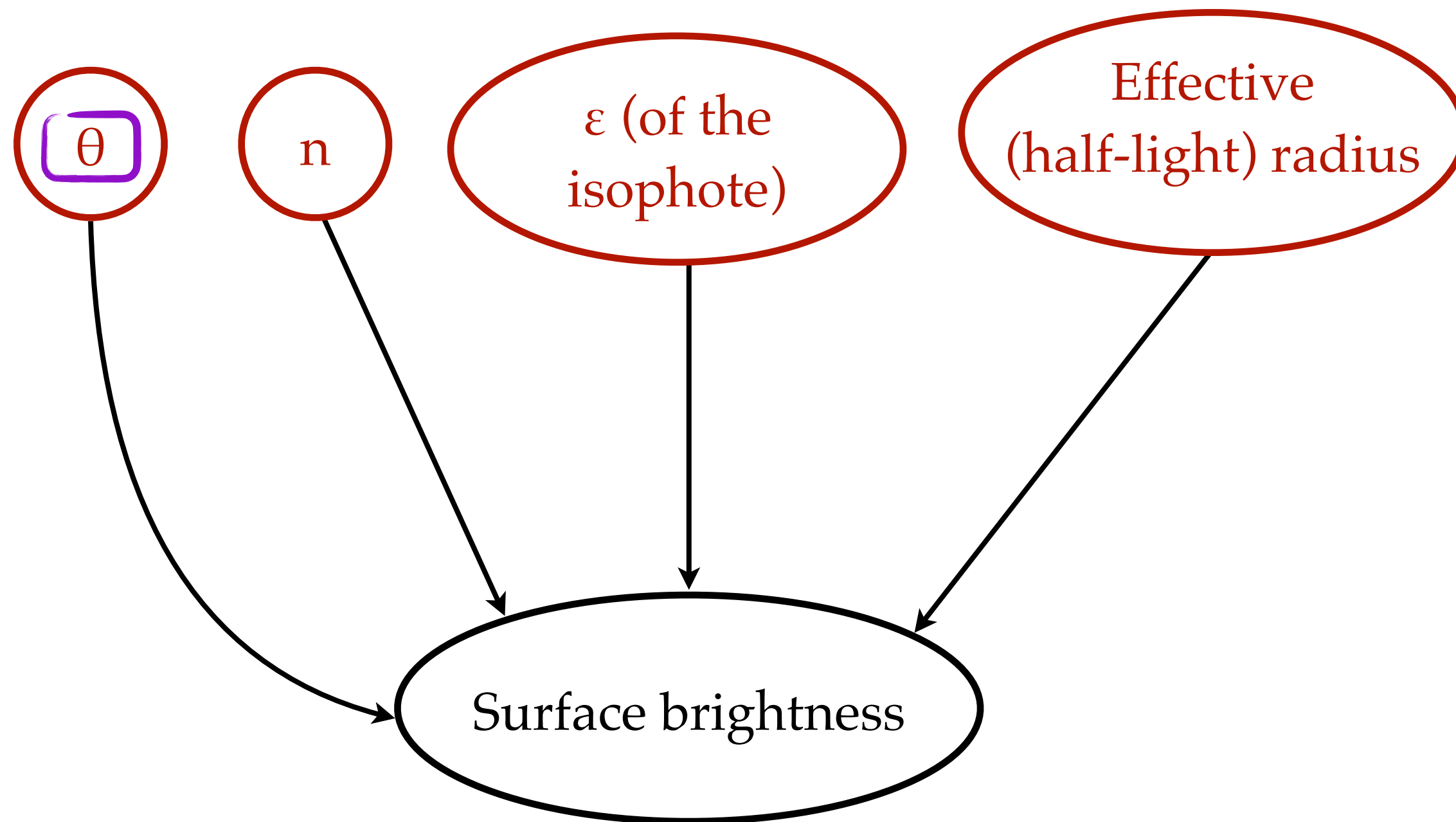
Galaxy modelling

First-approach :

simple Sérsic profile, independent parameters

DAG

Directed Acyclic Graph



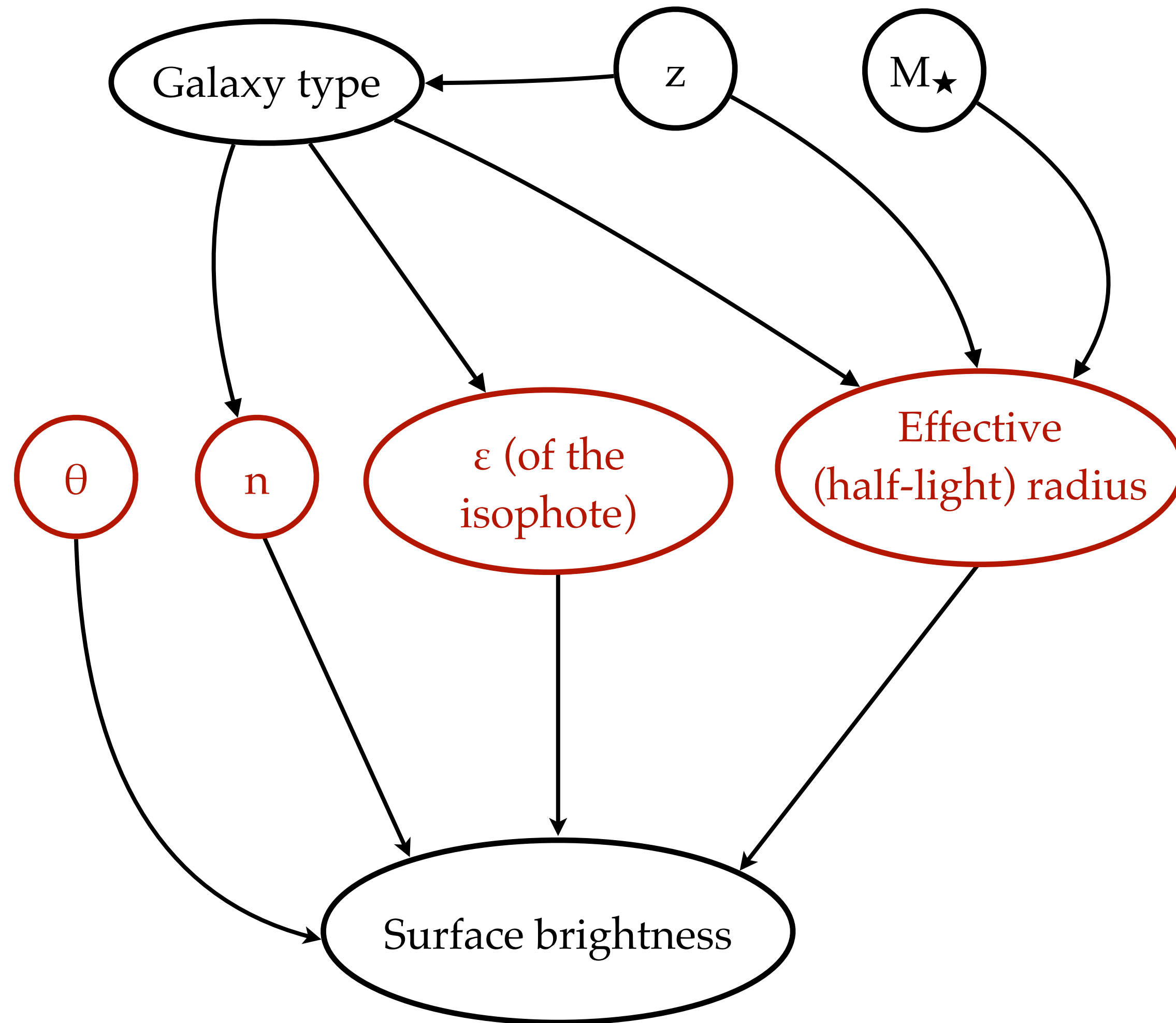
```
sersic_profile = dict(
    theta      = {"func": draw_position_angle, "kwargs": {}},
    n          = {"func": draw_sersic_index, "kwargs": {}},
    ellipticity = {"func": draw_ellipticity, "kwargs": {}},
    r_eff       = {"func": draw_reff, "kwargs": {}},
    surface_brightness = {"func": sersic_surface_brightness,
        "kwargs": {"theta": "@theta", "n": "@n",
            "ellip": "@ellipticity", "r_eff": "@r_eff"}},
)

mdag = modeldag.ModelDAG(sersic_profile)
```

see *modeldag* doc

 Sérsic profil parameters

Galaxy modelling prospects

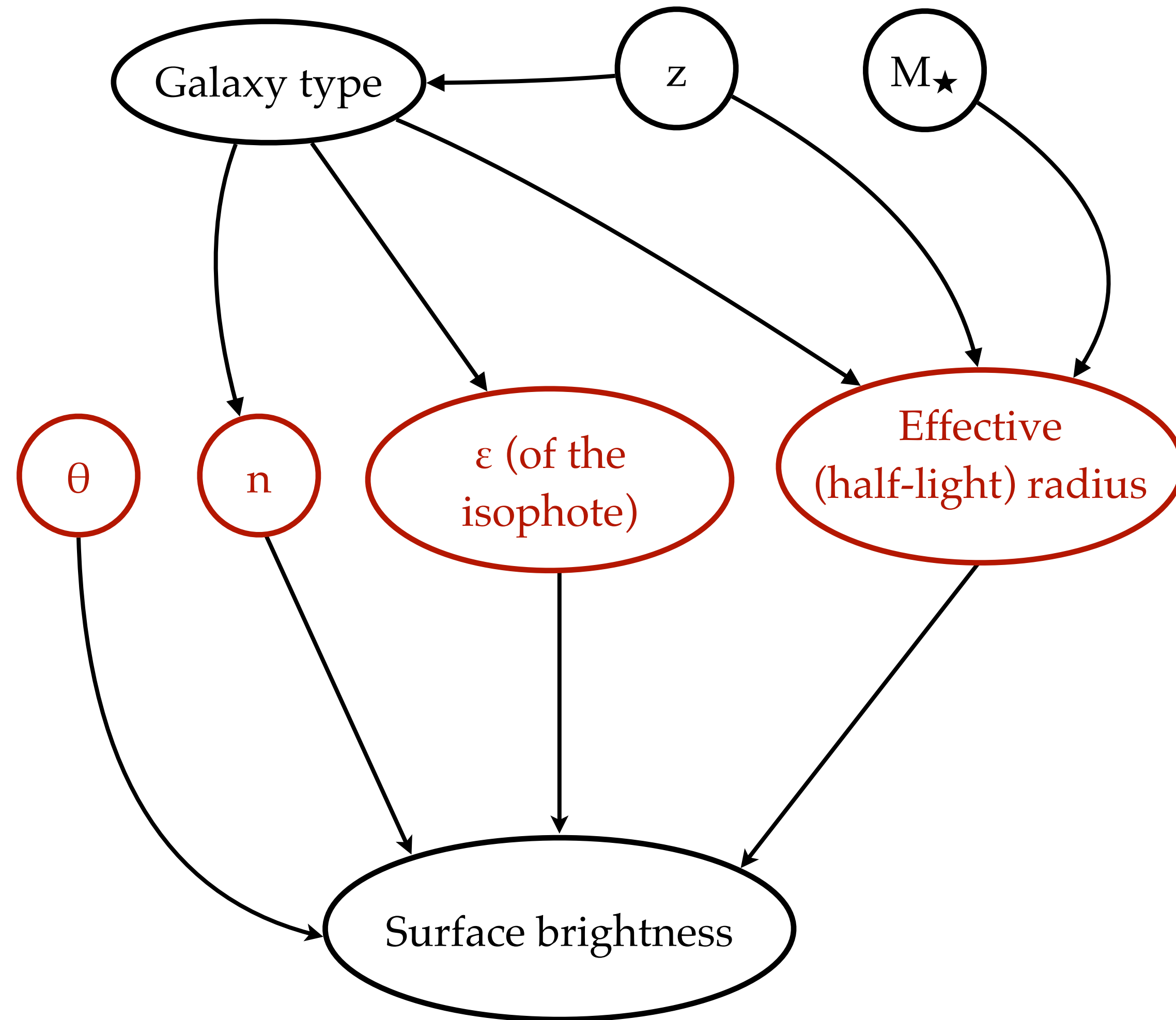


To more complex models :

- Galaxy properties (Galaxy type + $M_{\star}$)
 - > Metallicity, SFR, SFH
 - > SN progenitor age, rate, luminosity

 Sérsic profil parameters

Galaxy modelling prospects

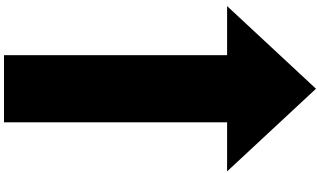
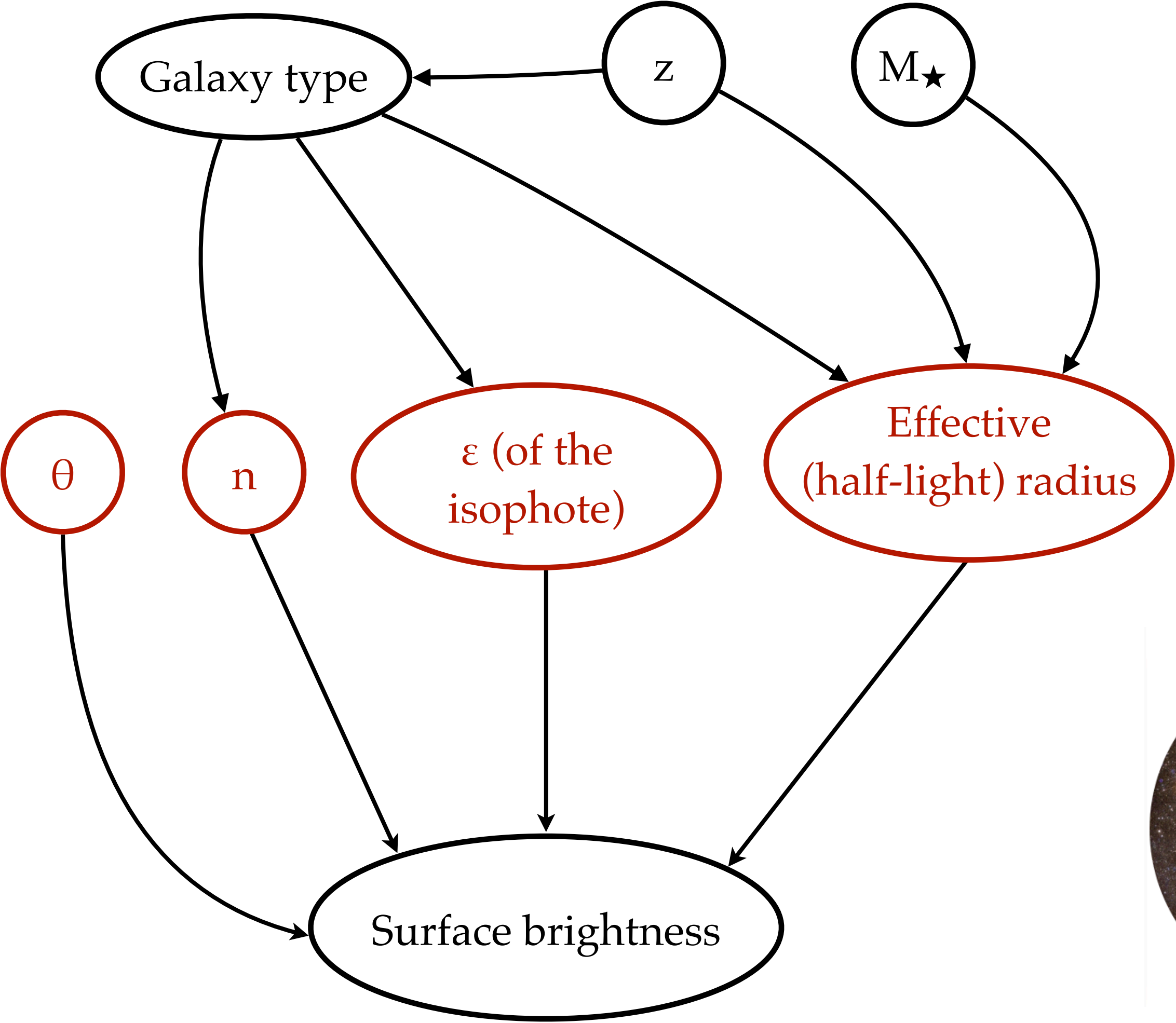


To more complex models :

- Galaxy properties (Galaxy type + $M_{\star}$)
—> Metallicity, SFR, SFH
—> SN progenitor age, rate, luminosity
- Double-Sérsic profile to describe region of a galaxy (spiral: $n_{\text{bulge}} \neq n_{\text{disc}}$) (Tang et al.25)

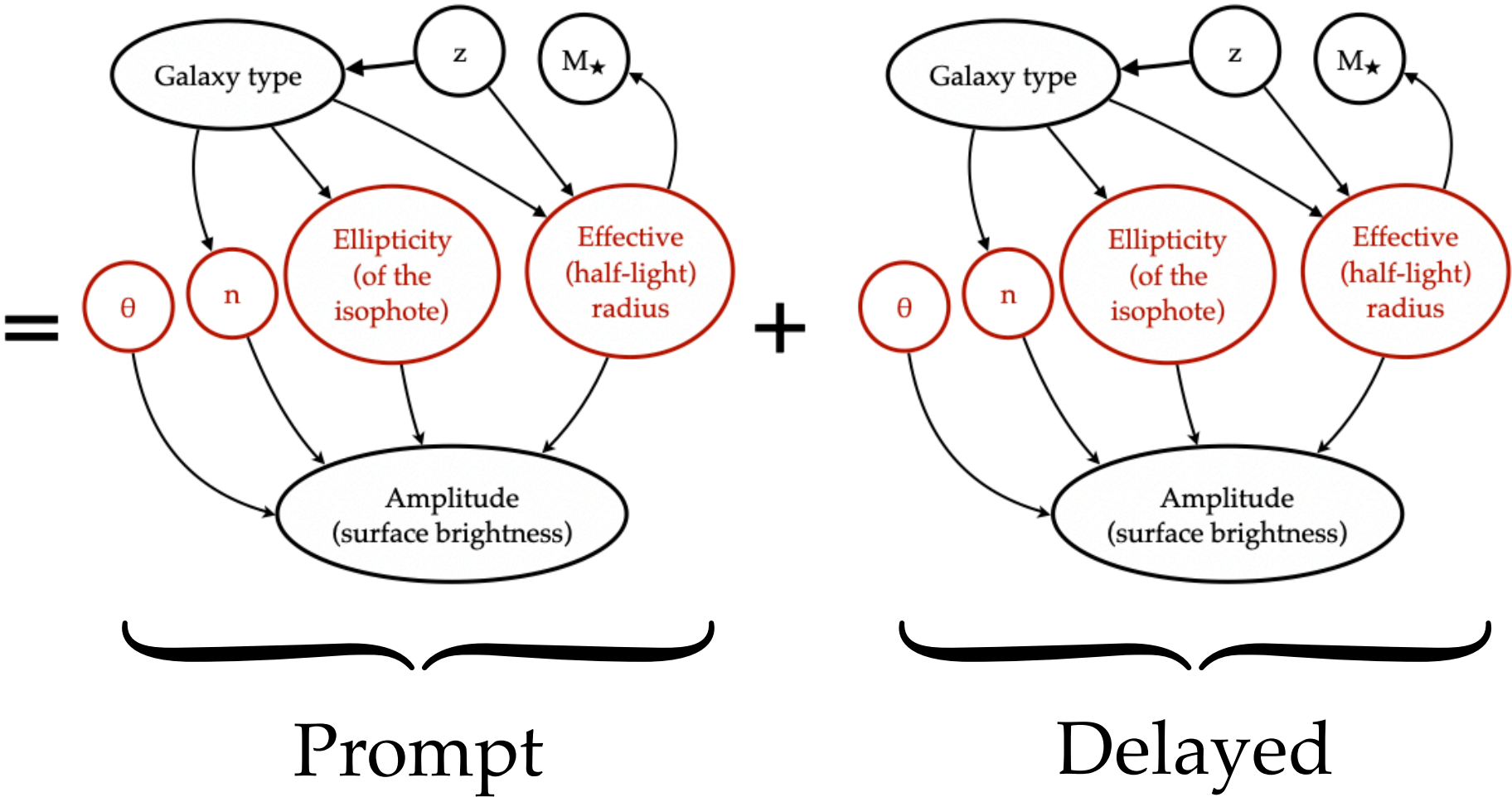
Sérsic profil parameters

Galaxy modelling prospects



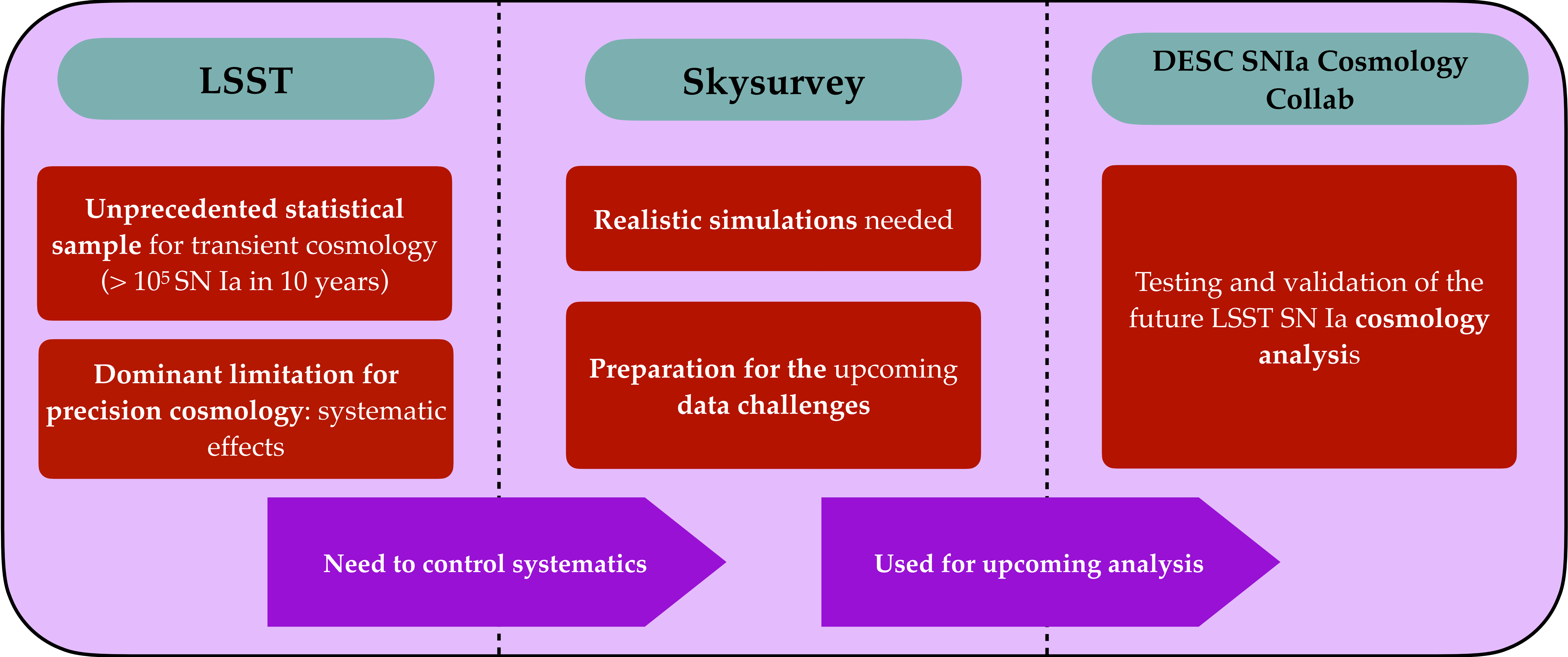
To more complex models :

- Galaxy properties (Galaxy type + M_★)
—> Metallicity, SFR, SFH
—> SN progenitor age, rate, luminosity
- Double-Sérsic profile to describe region of a galaxy (spiral: n_{bulge} ≠ n_{disc}) (Tang et al.25)
- Double-Sérsic profile for SN progenitors (prompt, delayed) (≠ SFR and regions of the galaxy)

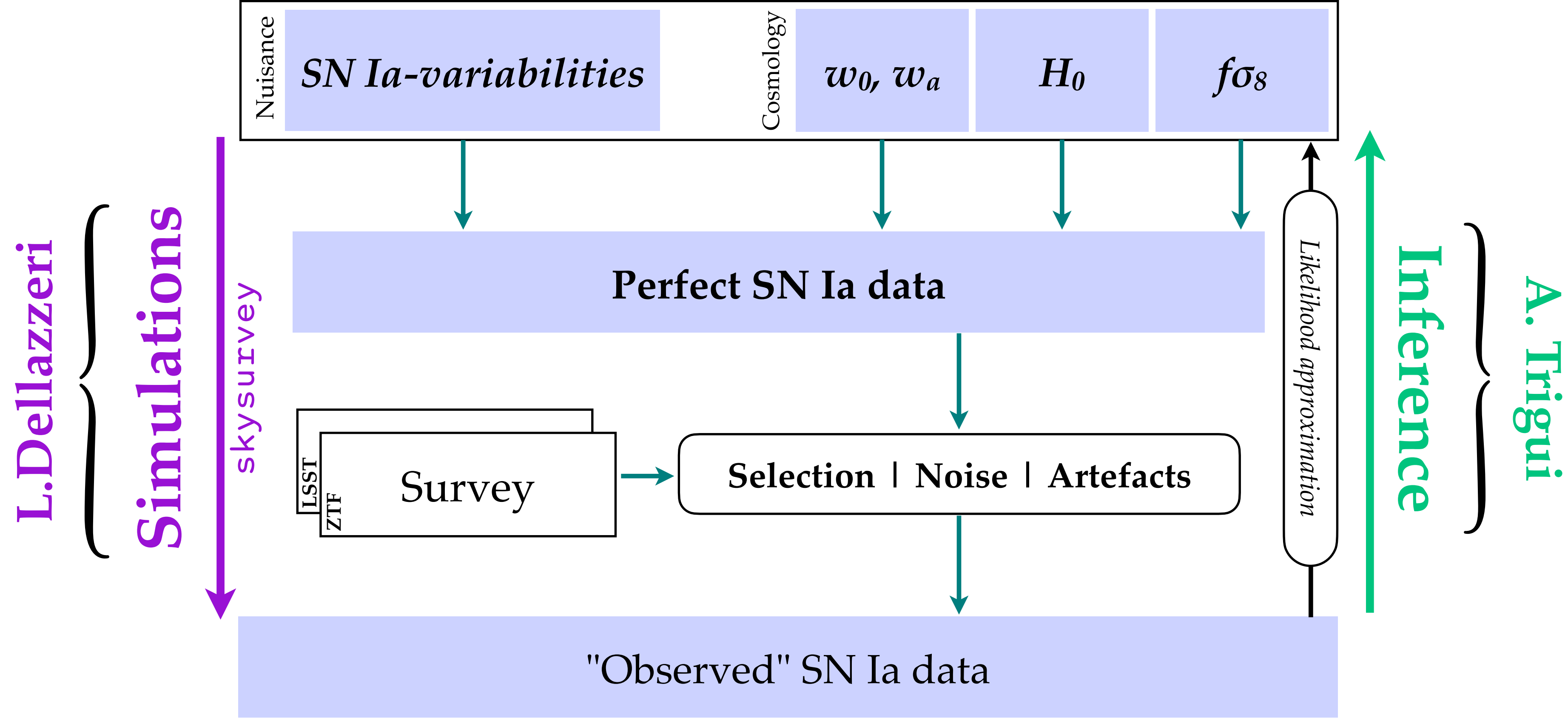


Sérsic profil parameters

Conclusion



Annexes



From SNANA to skysurvey

SNANA

(Kessler et al. 2009)

Lightcurves fitter
Cosmology fitter (BBC)
Transient simulations

SNANA is central
for cosmological analyses...

Yet, hard to install and complex to use.

(Way to go: ssh to a private Chicago cluster...)

(Coded in a mix of C, Python and Fortran)

skysurvey

(Rigault et al. 2026, *submitted*)

Aims to replace the simulation part of
SNANA

Transient simulations

- Simple **pip** install skysurvey
- Run locally on a laptop
- Modular, user-friendly and easy to custom targets, models, surveys....

Pre-Built Transients

Transient templates and sources are built on top of **SNCosmo** (Barbary et al. 2025)

Any **SNcosmo built-in source** is available:

Type Ia Supernovae

snia = skysurvey.SNeIa()

Transient Time Serie

sn_07pk = skysurvey.TSTransient("v19-2007pk-corr")

Kilonova

kilonova = skysurvey.Kilonova()

Supernova Types

snii = skysurvey.SNeII.from_draw(1000)

"Collection
Transient Time Series"

SNII | SNIIfb | SNIIn | SNIIfb | SNIIfc | SNIIfcBL

23 12 6 12 7 6

(Vincenzi et al. 2019)

Customization is *easy*
rate, redshift range, absolute
magnitude distribution,...

see skysurvey doc for how to change the rate of a
target

see tutorial "how to create a new transient class" on the skysurvey doc

Easy to build *complex* transient

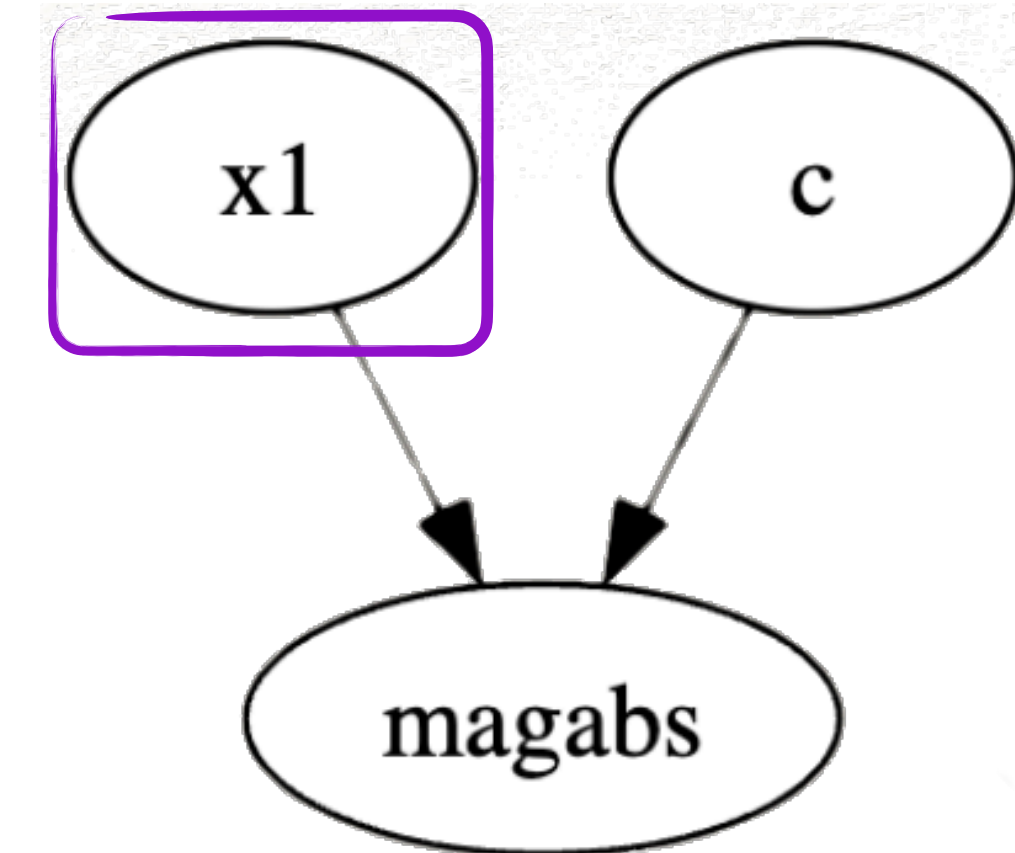
DAG

```
# ----- #
#   Your functions #
# ----- #
def tripp98(x1, c, alpha=-0.14, beta=3.3, sigmaint=0.1, mabs=-19.3):
    """This is the Tripp 98 relation."""
    magabs = x1 * alpha + c * beta + mabs # natural SN Ia magnitude (non-standardized)
    magabs_scattered = np.random.normal(loc=magabs, scale=sigmaint) # add intrinsic scatter
    return magabs_scattered

# ----- #
#   Create the dict #
# ----- #
modeldict = {
    "x1": {"func": np.random.normal,
           "kwargs": {"loc": 0, "scale": 1}},
    "c": {"func": stats.lognorm.rvs,
          "kwargs": {"s": 0.7, "loc": -0.2, "scale": 0.2}},
    "magabs": {"func": tripp98,
               "kwargs": {"x1": "@x1", "c": "@c"}}
}

# ----- #
#   Simulate   #
# ----- #
mdag = modeldag.ModelDAG(modeldict)
data_sim = mdag.draw(1_000)
```

mdag.visualize()



see modeldag doc

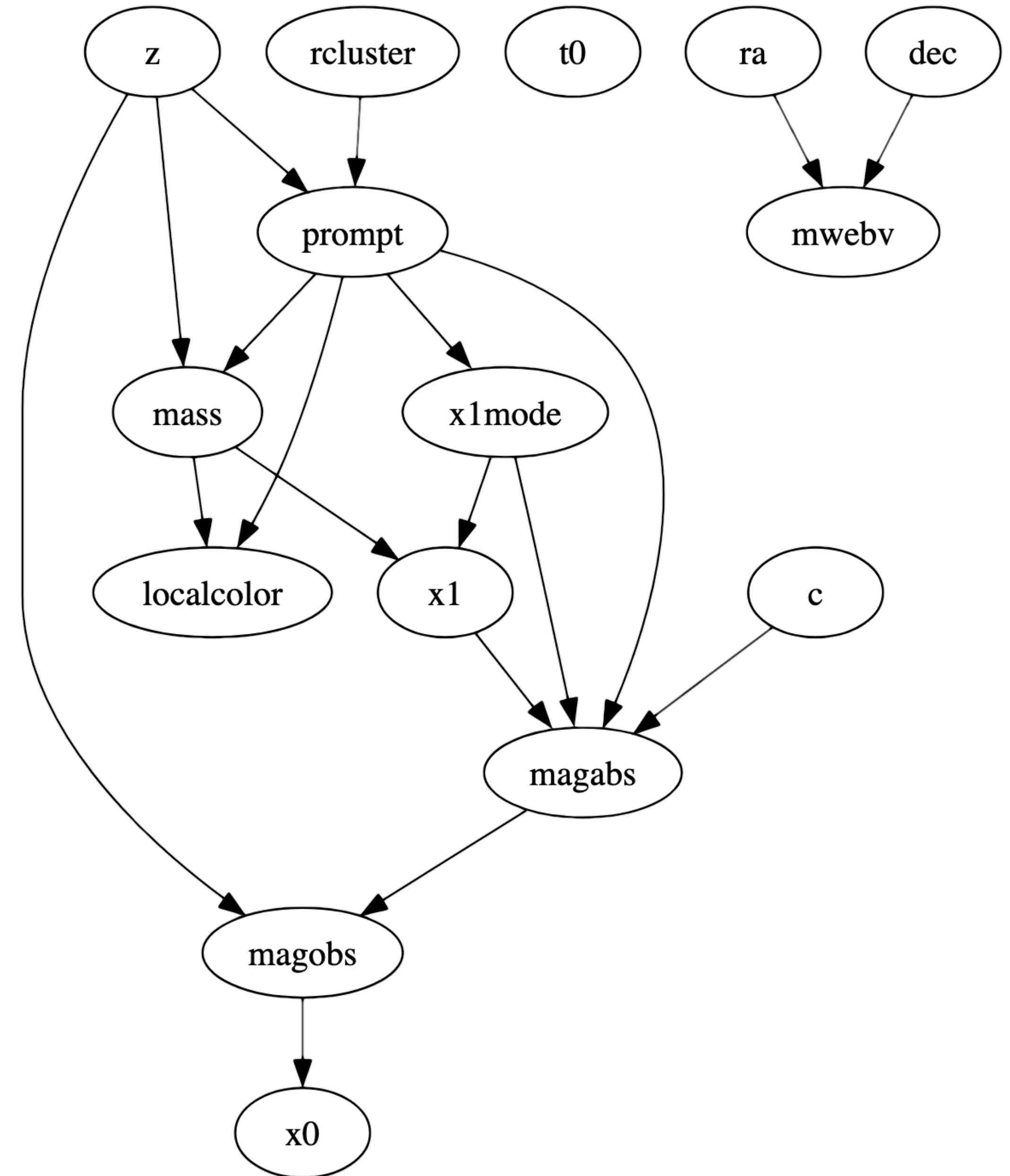
Easy to build complex transient

```
model_extension = {"prompt": {"func": ...,  
                             "kwargs": ...},  
                  "mass": {"func": ...,  
                           "kwargs": ...},  
                  ...  
}
```

```
import skysurvey  
snia = skysurvey.SNeIa.from_draw(1_000,  
                                model=model_extension)
```

see modeldag doc

Current SNe Ia “Age model”

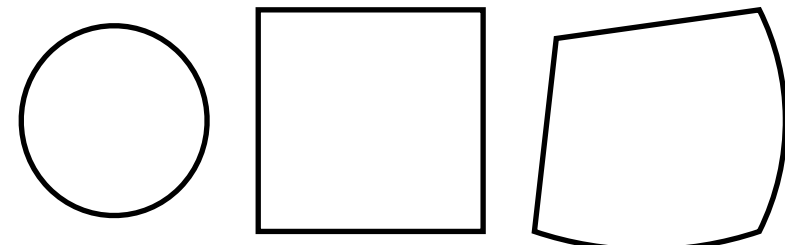


Build your own Survey

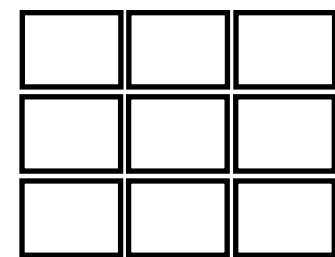
```
# Load the survey
survey = skysurvey.Survey.from_pointings(data, footprint=footprint)
```

footprint | *camera footprint in the sky*

shapely



Polygon



MultiPolygon

```
skysurvey.get_footprint("des")
```

```
import numpy as np
from shapely import geometry
from skysurvey.tools import utils

# footprint | 2-deg radius circle
footprint = geometry.Point(0,0).buffer(2)
```

data | *what was observed when, under which conditions*

pandas



ra, dec — Camera pointings

mjd — time in Modified Julian Date

band — name of the filter used

skynoise — level of the sky noise (unit of zp)

zp — depth of the image

gain — camera gain (e-/adu), used for noise

```
data["skynoise"] = np.random.normal(size=size, loc=200, scale=20)
```

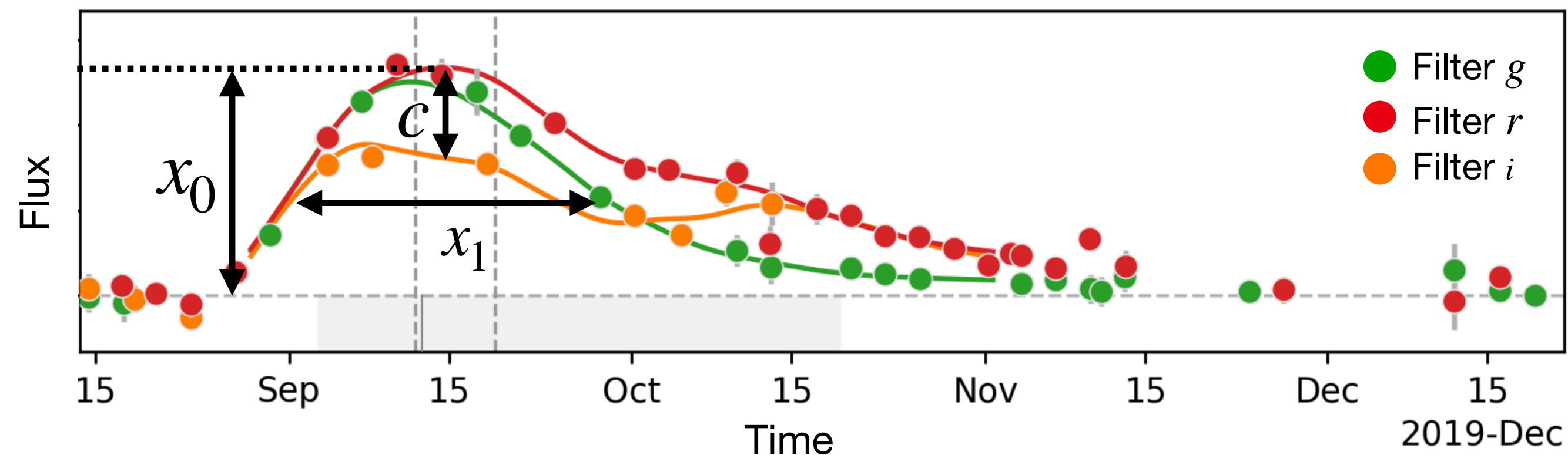

ZTF DR2

Zwicky Transient Facility :

- Located in Mount Palomar Observatory
- Large field of view
- High cadence (30s/ exposure)

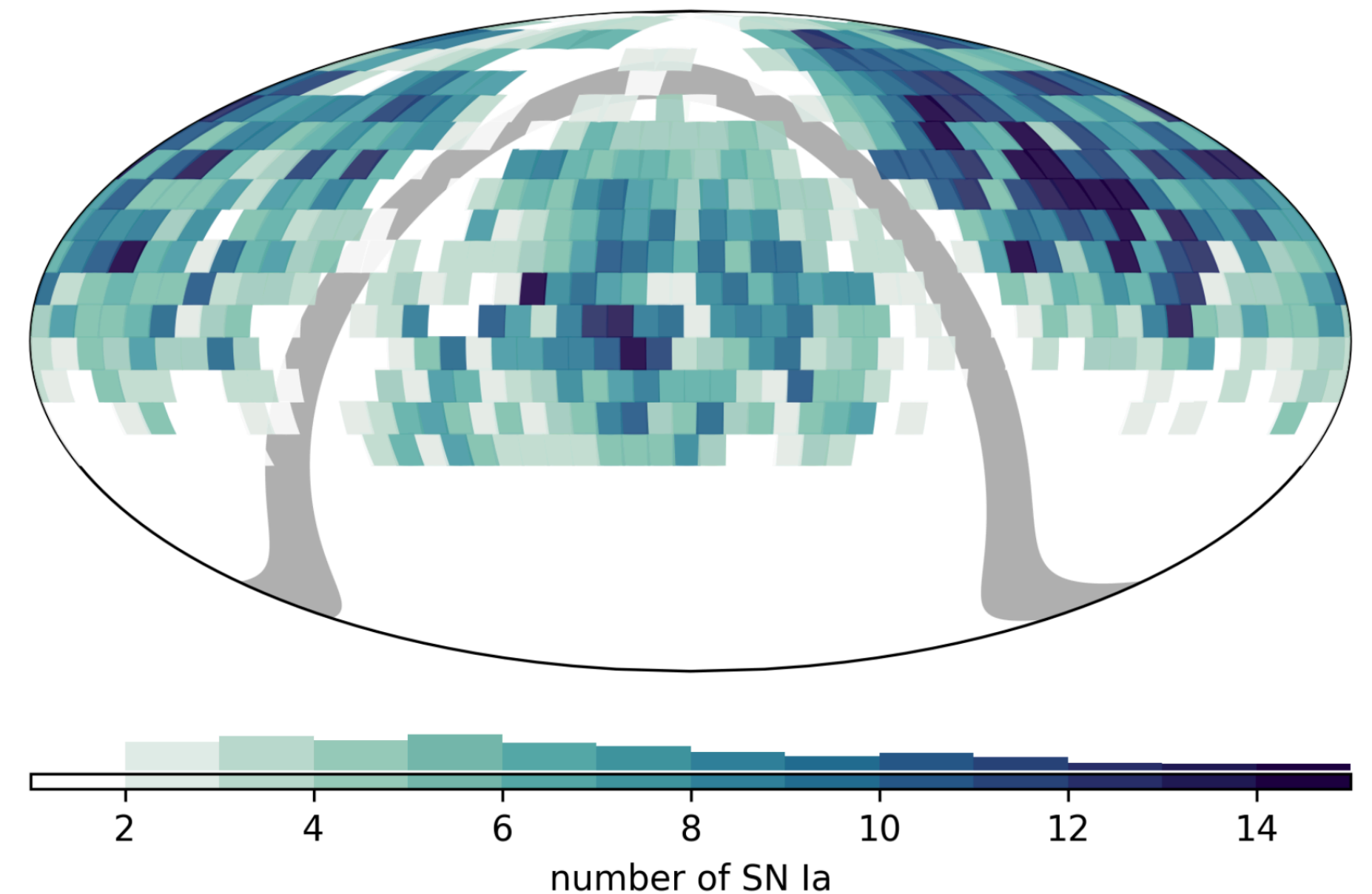
Data Release 2 :

- First and larger homogenous SNe Ia sample
- 3628 nearby events ($z < 0.3$)



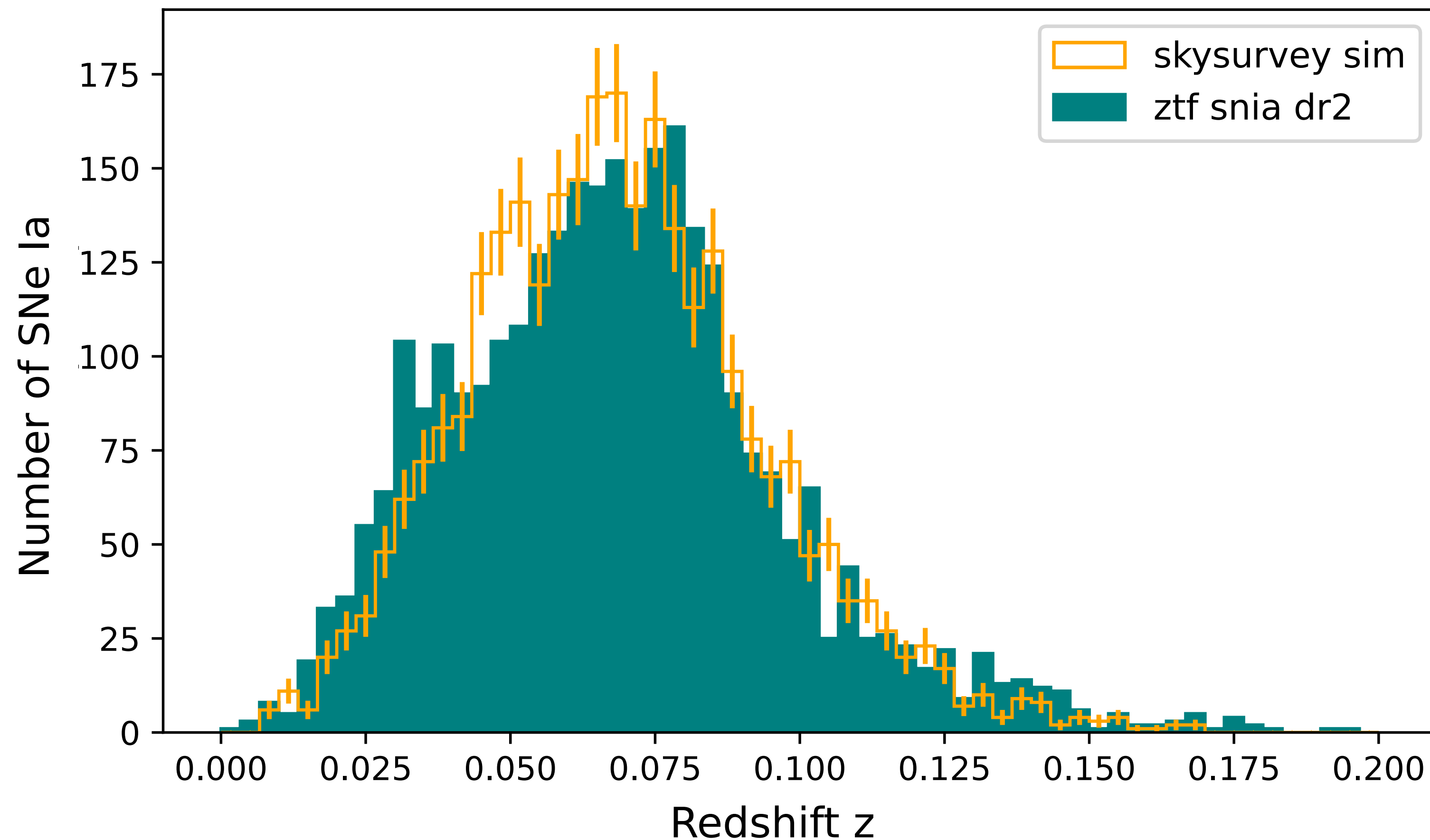
ZTF DR2 : ZTF19abunnnx

ZTF SN Ia DR2, data: ztfcosmo.in2p3.fr



DR2 Overview : Rigault et al 2025

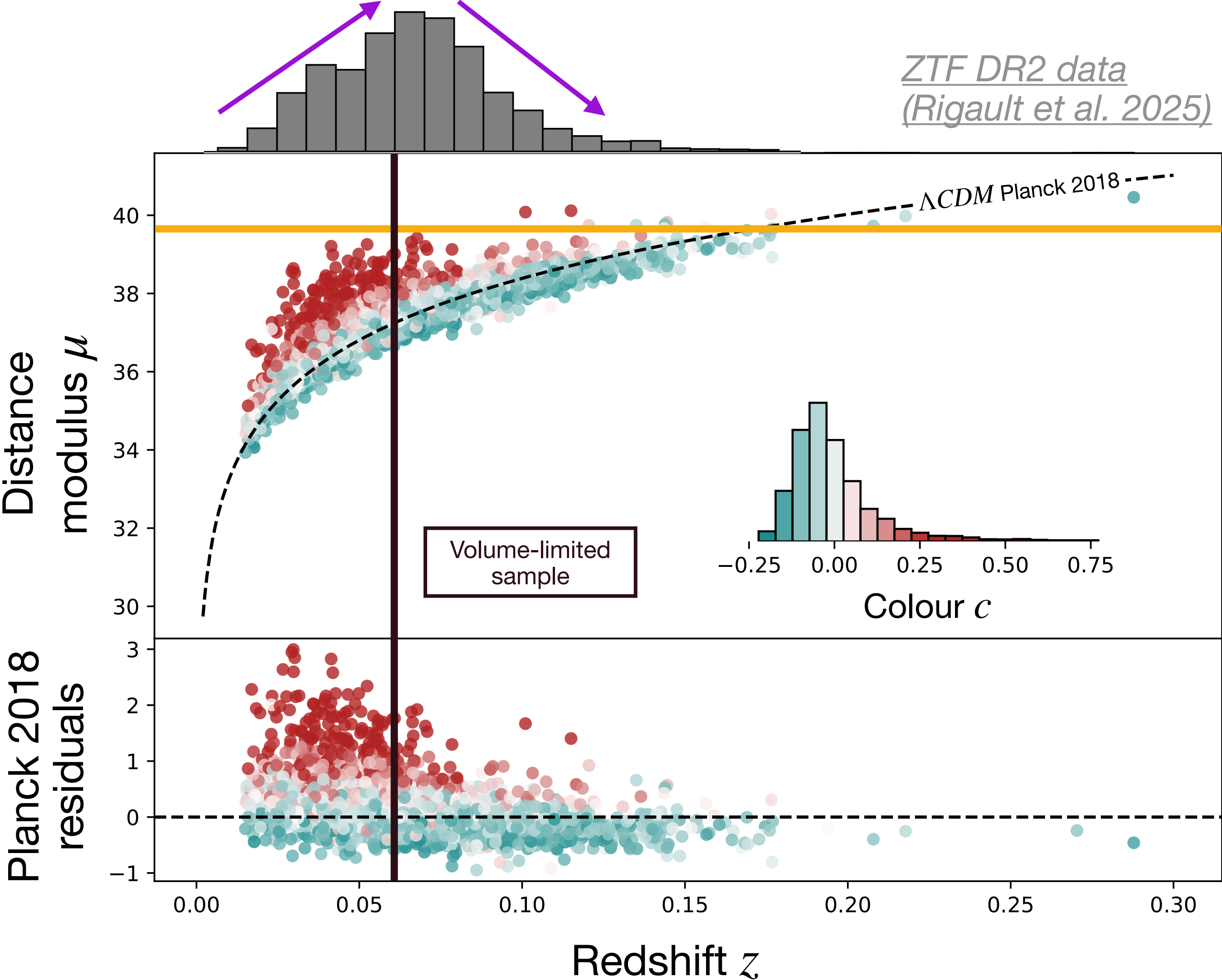
Skysurvey's state of the art



Assumptions :

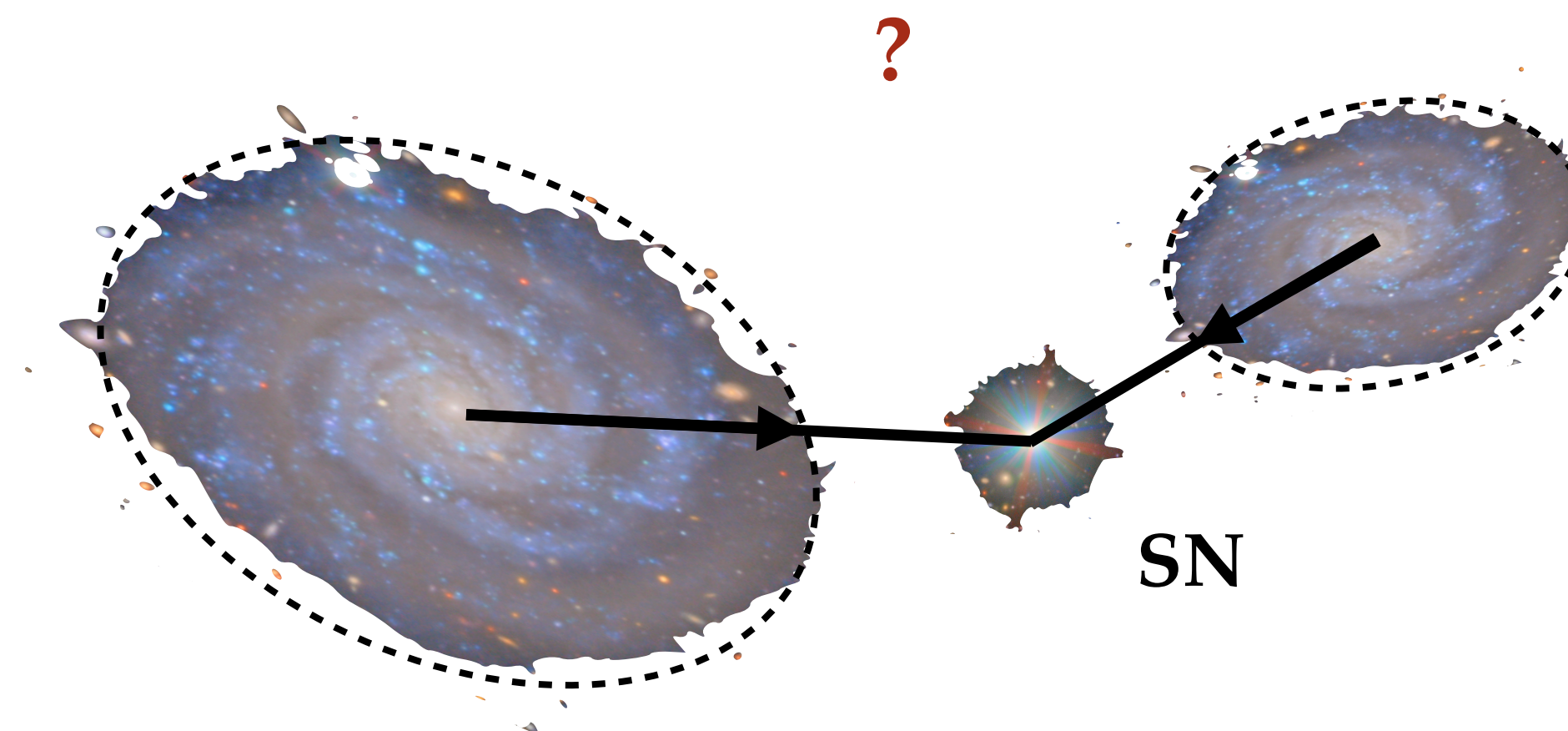
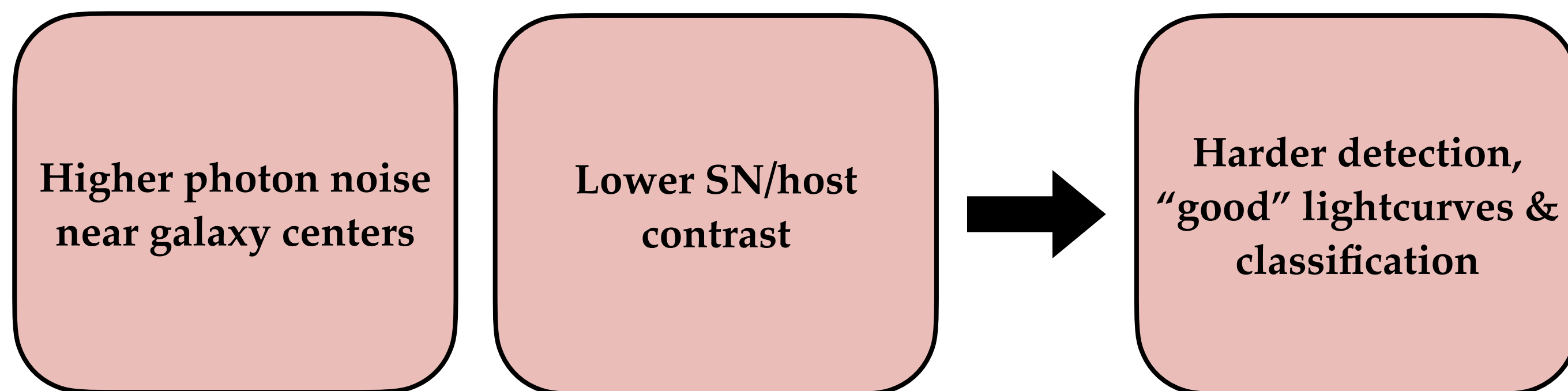
- Homogeneous and isotropic Universe
- Constant intrinsic SN Ia rate
- Simple ZTF DR2 selection effect

Hubble Diagram



Galaxy selection effects

Host-dependent selection effects:



Implementation in skysurvey:

