上海交通大學 SHANGHAI JIAO TONG UNIVERSITY

The 2nd Shanghai Assembly on cosmology and structure formation

SJTU

Constructing LSS analysis pipeline for CSST slitless spectroscopic surveys

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Oct 30-Nov 3, 2023

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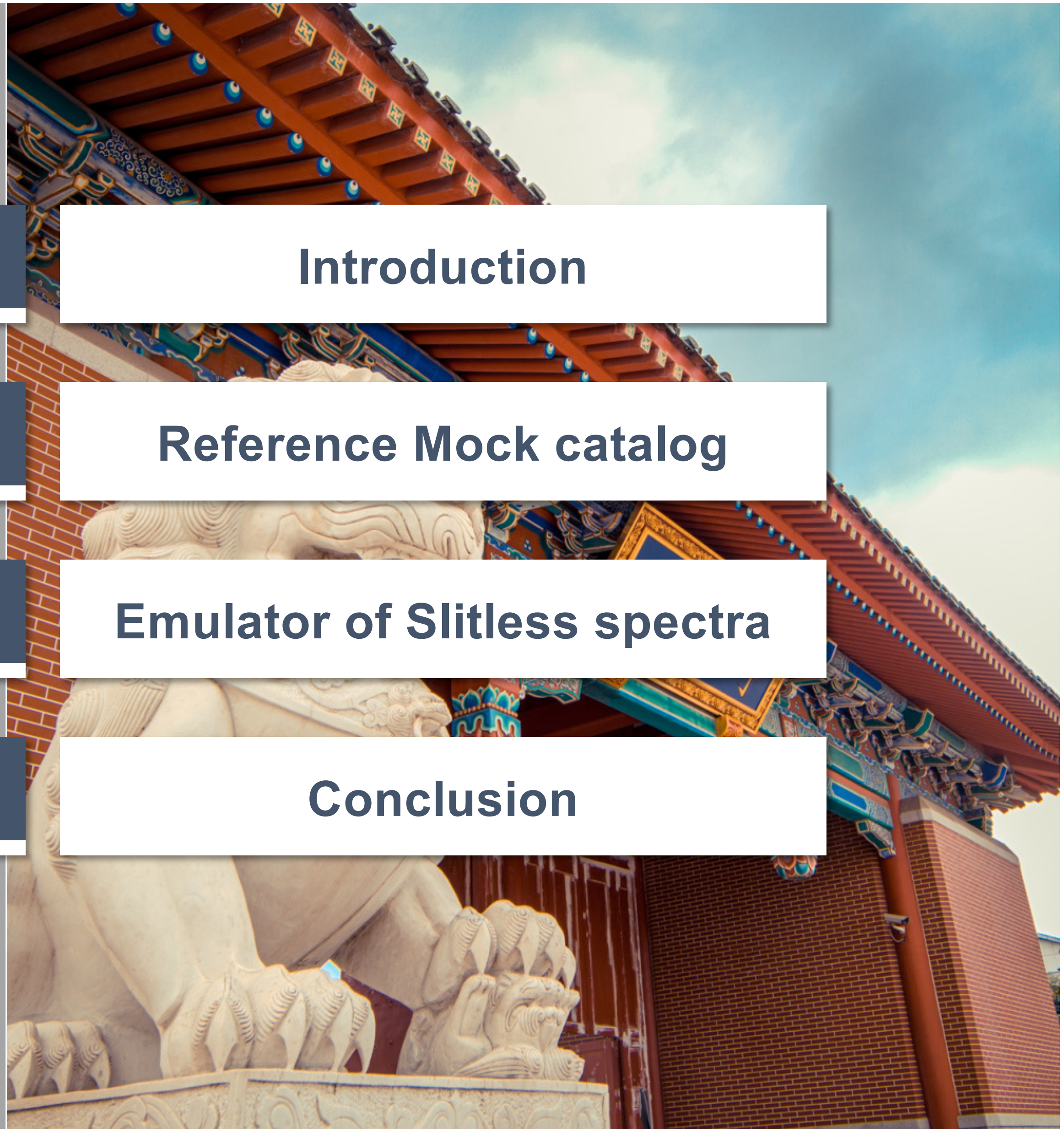
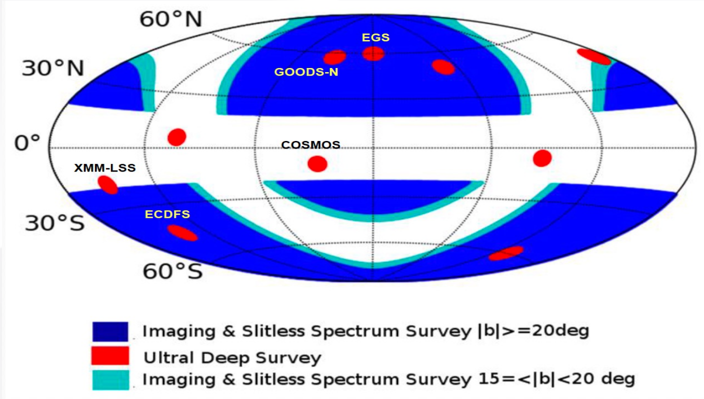


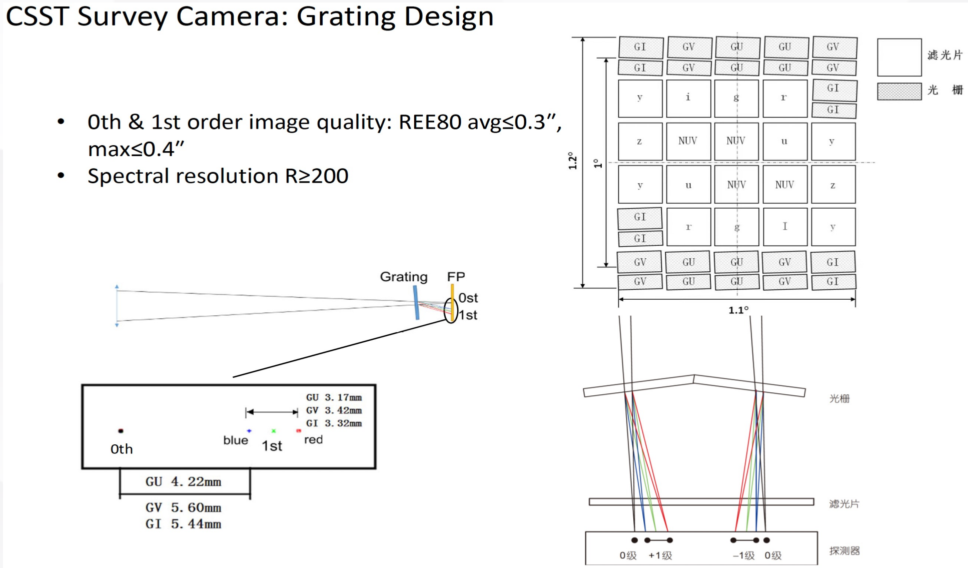
Introduction of CSST Slitless Spectroscopy survey

- **17500deg^2 multiband imaging observations:**

  255-1000nm, 7 filters, Sensitivity > 25.5
- **17500deg^2 slitless spectroscopic observations**

  255-1000nm, R ~ 200

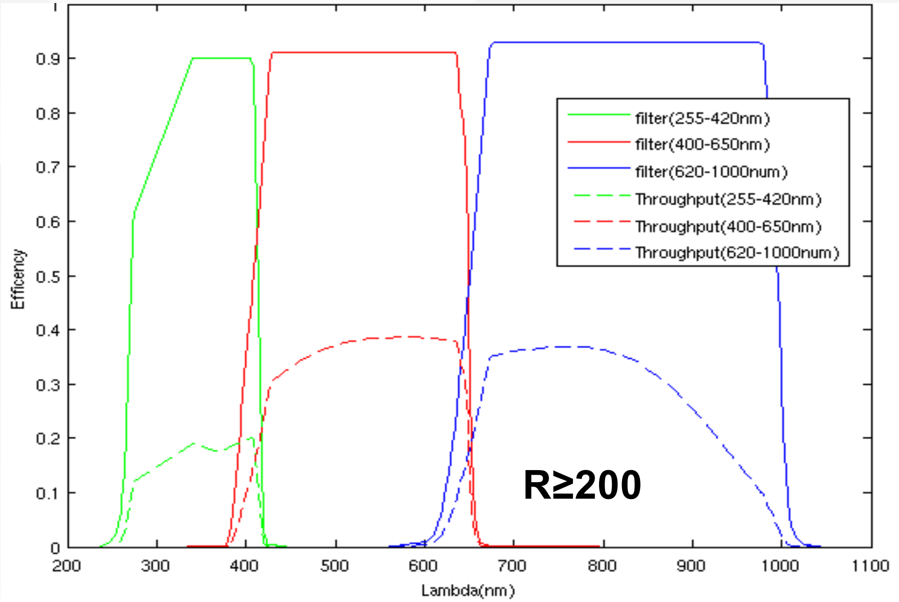


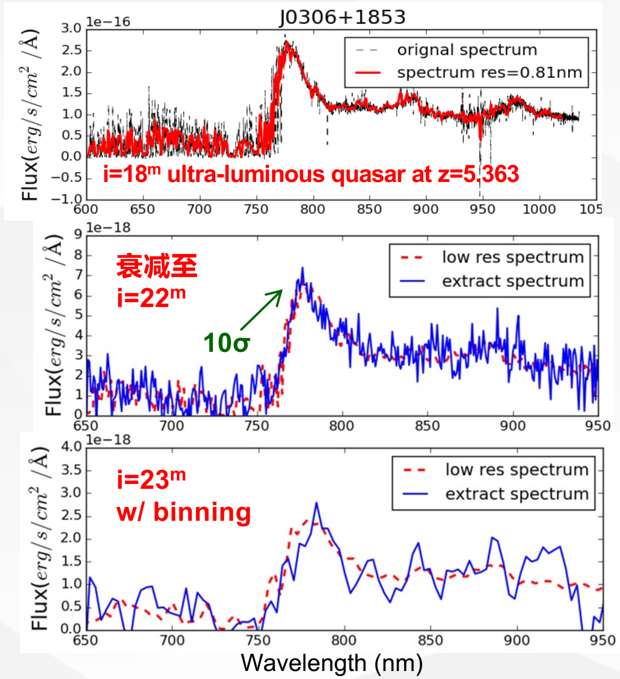


Credit@H. Zhan and F.S. Liu

CSST ~ 2025 2m

The magnitude limits for slitless specroscopic surveys



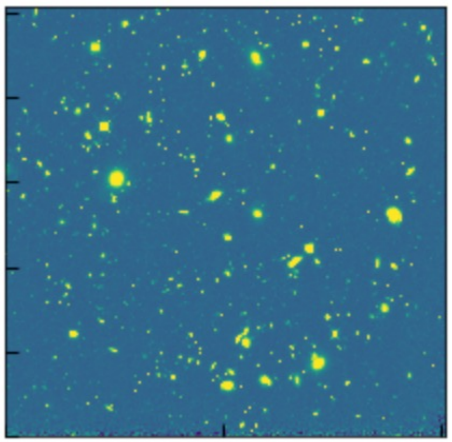


	t_{exp}	GU	GV	GI
17500□°	4×150s	20.5	21.0	21.0
400□°	16×250s	21.8	22.2	22.1

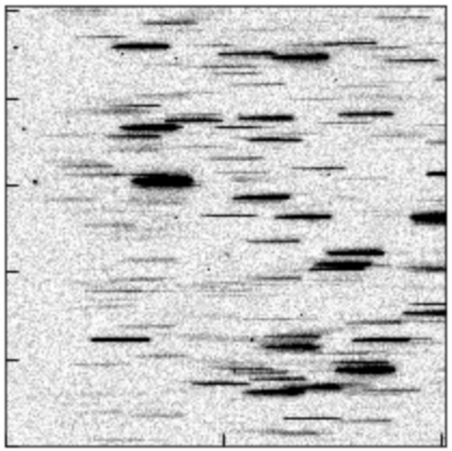
i band 20σ ~2 ELG/square arcmin（based on HST PEARS results）

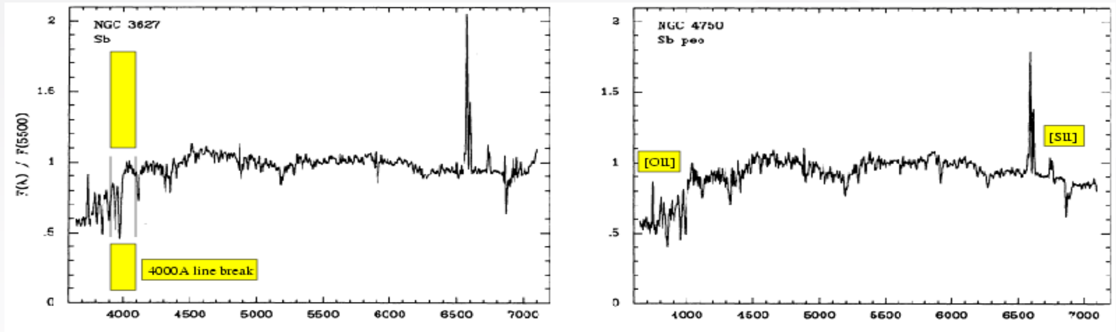
Suffer from incompleteness and contaminations

Mimic a CSST-like image



Simulate the dispersed spectra





- ➢ Low resolution: redshift successful rate is low, -- incomplete
- ➢ Overlap effect along the dispersion direction, -- contamination
- ➢ There are multi orders of spectra for a give source, -- contamination

- We need to use reference mock galaxy redshift surveys (MGRS) to evaluate the impact of these selection effects on the cosmological and galaxy formation probes!

Task 1: building an ideal reference MGRS

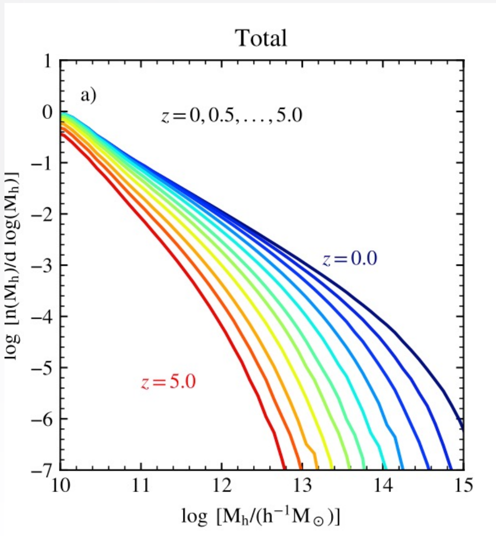
Simulation IO → *Subhalo catalog*
9tian/Uchuu/Mill/ELUCID

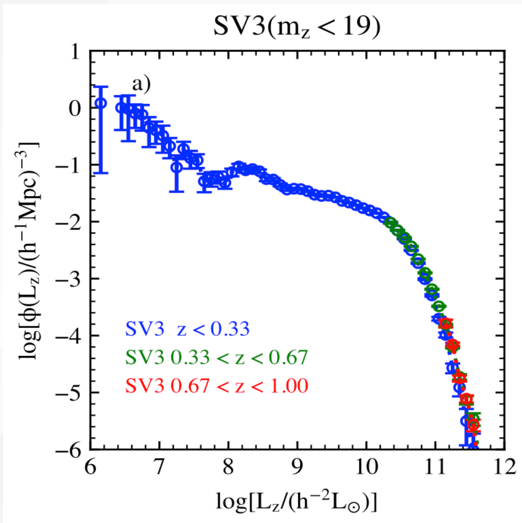
Light-cone build → Light-cone *catalog*
To build from simulation box
Or input a lightcone catalog

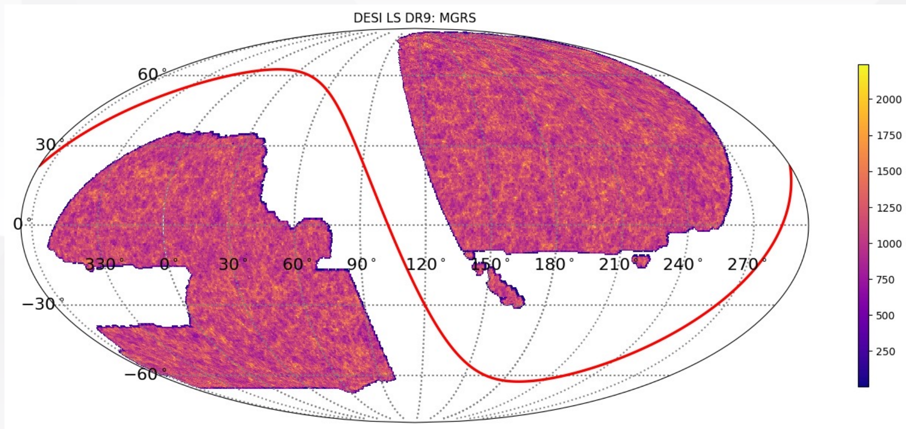
SHAM/HOD/CLF → *Galaxy catalog*
Assign luminosity…

Galaxy properties → assign properties
multi-bands photometry
stellar mass, images

Selection effect → Observed catalog
Geometry, flux limit,
foreground mask







https://gax.sjtu.edu.cn/data/CSST/CSST.html

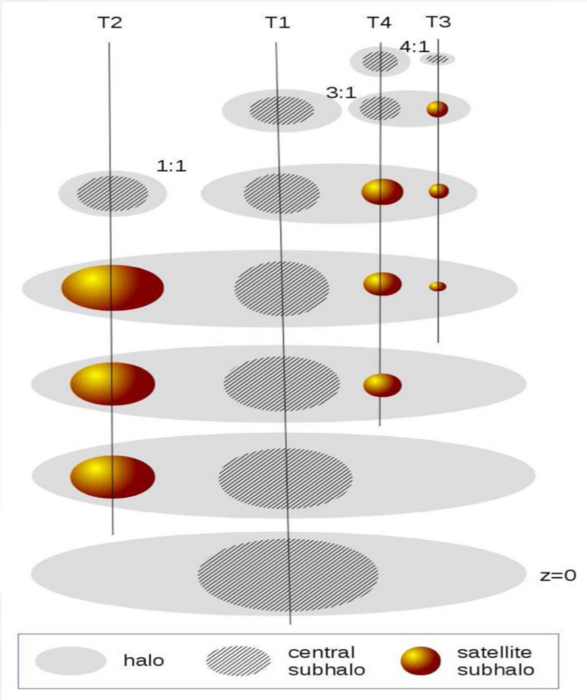
Gu et al. 2023, MNRAS submitted

Step 1: Using the most advanced 9tian subhalo catalog/light-cone

Simulation IO → Light-cone build

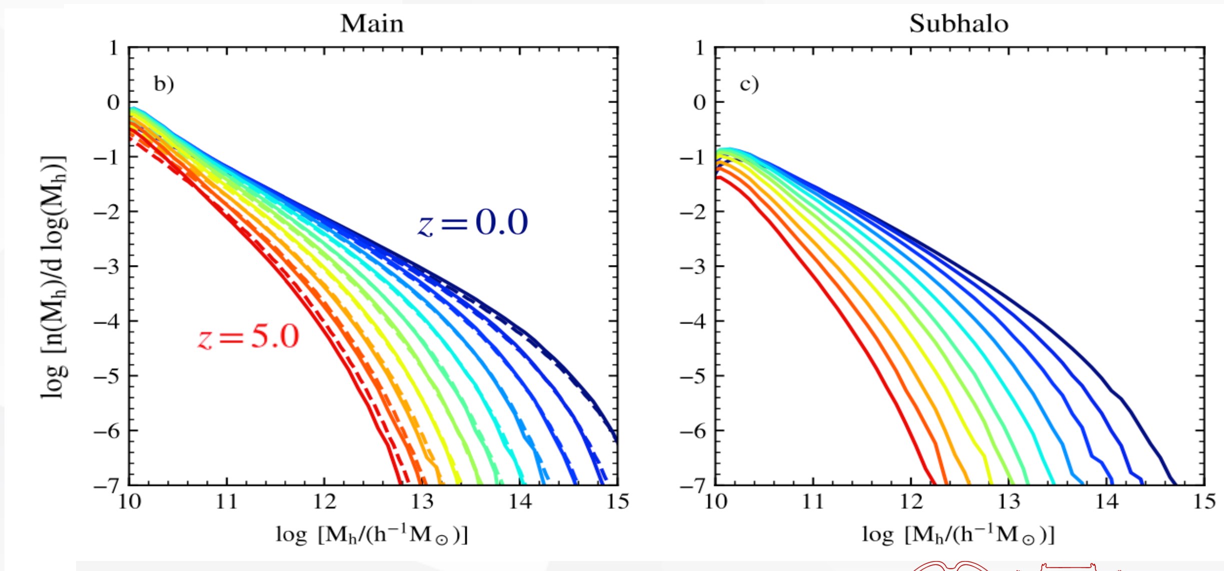
Subhalo catalog
9tian/Uchuu/Mill/ELUCID

Light-cone catalog
To build from simulation box
Or input a lightcone catalog



One high-resolution N-body simulation from Jiutian simulation suite.

- The Planck-2018 cosmology
- Box of 1 Gpc/h with 6144^3 particles
- Particle mass: $m_p = 3.723\times10^8\ h^{-1}M_\odot$
- Subhalo identification (HBT+)
- >200 (20) particles for halo (galaxy)



HBT+ Han et al. 2018

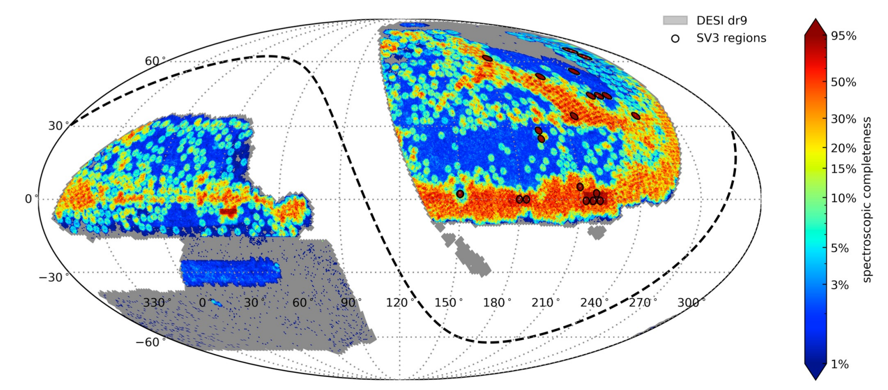
Step 2: Using the most advanced DESI SV3 luminosity functions

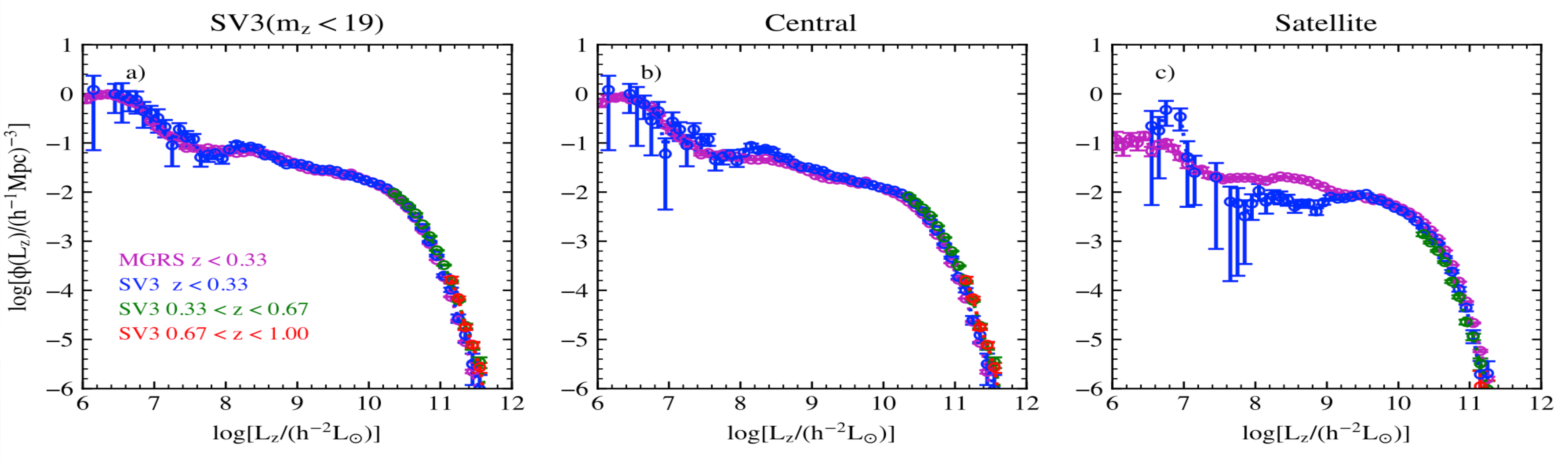
Simulation IO → Light-cone build → SHAM/HOD/CLF

Subhalo catalog
9tian/Uchuu/Mill/ELUCID

Light-cone catalog
To build from simulation box
Or input a lightcone catalog

Galaxy catalog
Assign luminosity…





Wang et al. 2023, in premaration

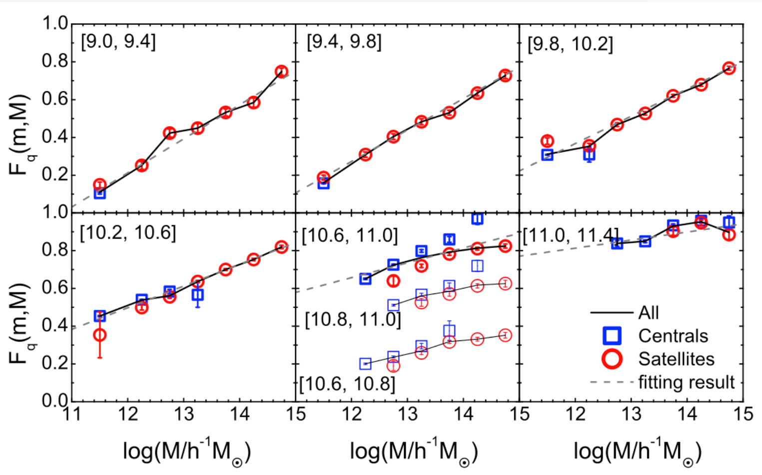
Step 3: Assign other galaxy properties using DESI observation

Simulation IO → *Subhalo catalog* — *9tian/Uchuu/Mill/ELUCID*

Light-cone build → *Light-cone catalog* — *To build from simulation box Or input a lightcone catalog*

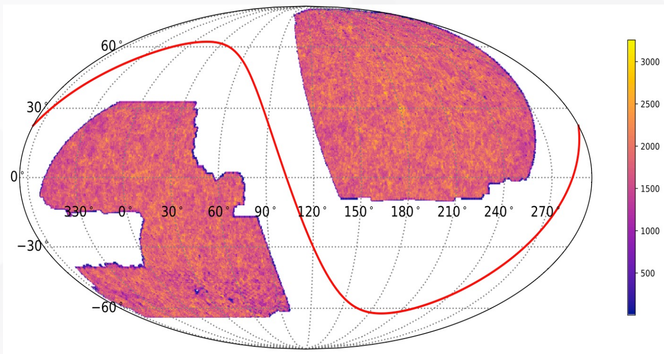
SHAM/HOD/CLF → *Galaxy catalog* — *Assign luminosity…*

Galaxy properties → assign properties — *multi-bands photometry stellar mass, images*



The quench fraction of galaxies is almost determined only by 2 parameters!

Wang et al. 2018, 2020



DESI LS group catalogs contain halo mass, stellar mass, luminosity information.

Yang et al. 2021

Mock	DESI
redshift	redshift
luminosity	luminosity
halo mass	group mass

Each mock galaxy is matched with one galaxy in DESI LS observation.

Step 3: Assign other galaxy properties using DESI observation

Simulation IO → Light-cone build → SHAM/HOD/CLF → Galaxy properties

Simulation IO
Subhalo catalog
9tian/Uchuu/Mill/ELUCID

Light-cone build
Light-cone catalog
To build from simulation box
Or input a lightcone catalog

SHAM/HOD/CLF
Galaxy catalog
Assign luminosity…

Galaxy properties
assign properties
multi-bands photometry
stellar mass, images

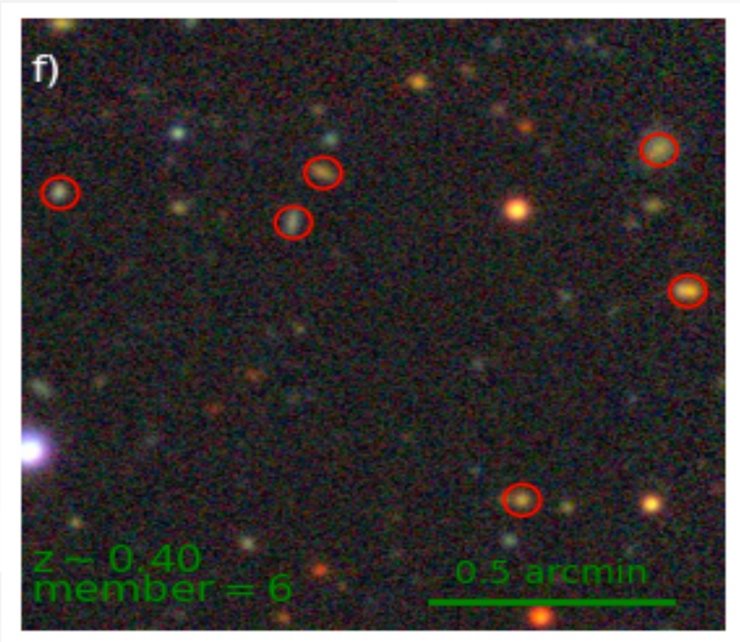


image of a group from DESI LS dr9

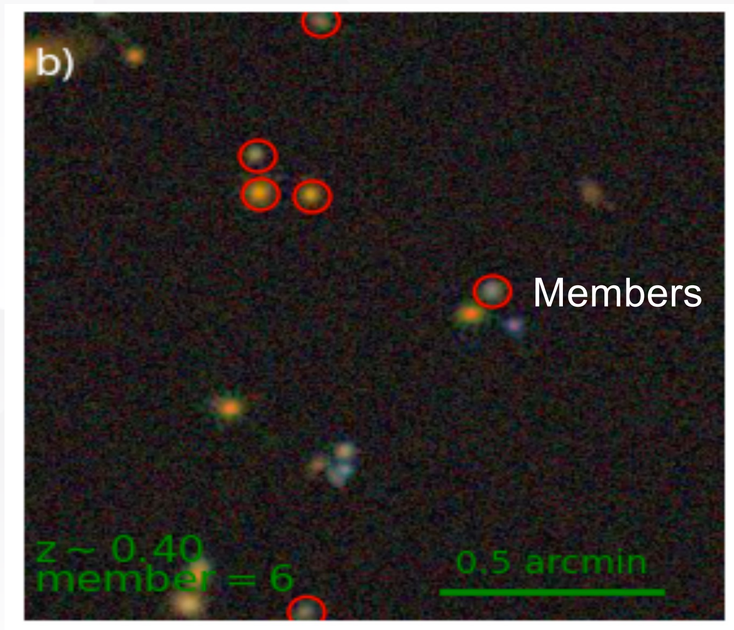
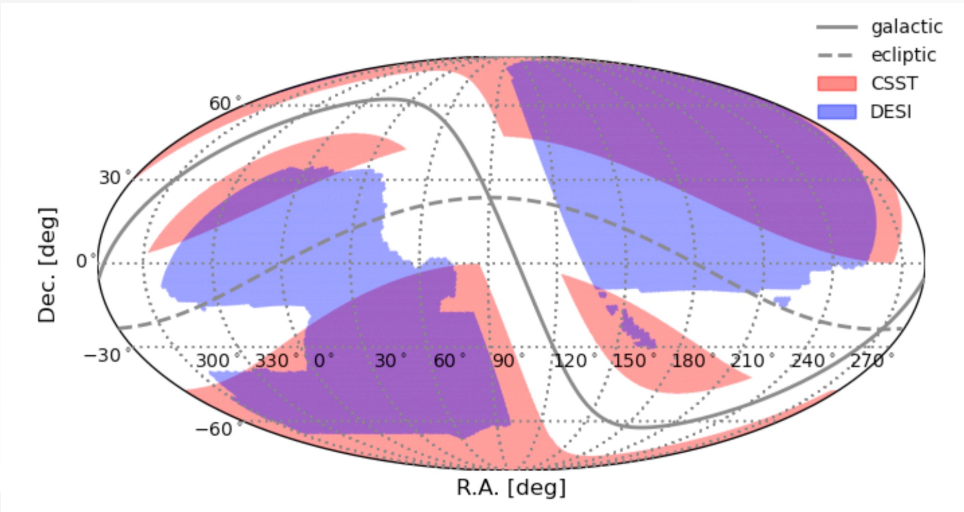


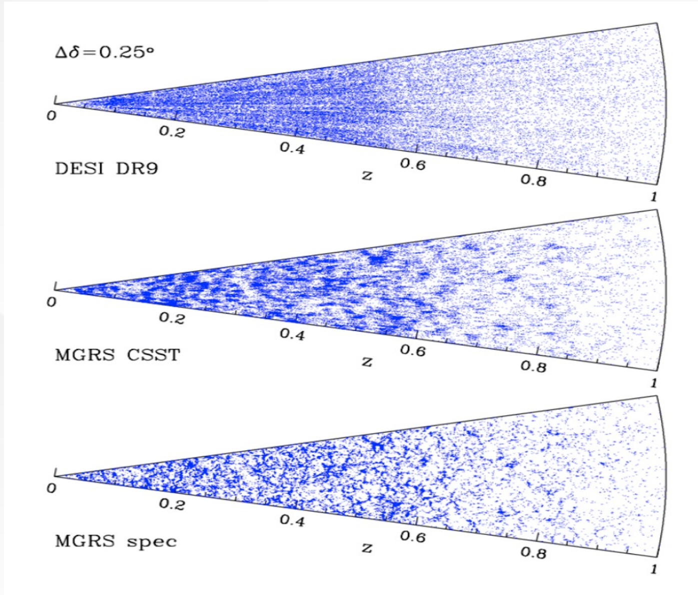
image of a halo from MGRS

Step 4: Apply survey geometry selection

Simulation IO → Light-cone build → SHAM/HOD/CLF → Galaxy properties → Selection effect

Simulation IO	Light-cone build	SHAM/HOD/CLF	Galaxy properties	Selection effect
Subhalo catalog	Light-cone *catalog*	*Galaxy catalog*	assign properties	Observed catalog
9tian/*Uchuu/Mill/ELUCID*	*To build from simulation box* *Or input a lightcone catalog*	*Assign luminosity…*	*multi-bands photometry* *stellar mass, images*	*Geometry, flux limit,* *foreground mask*





Step 4: Apply survey forground mask

Simulation IO → **Light-cone build** → **SHAM/HOD/CLF** → **Galaxy properties** → **Selection effect**

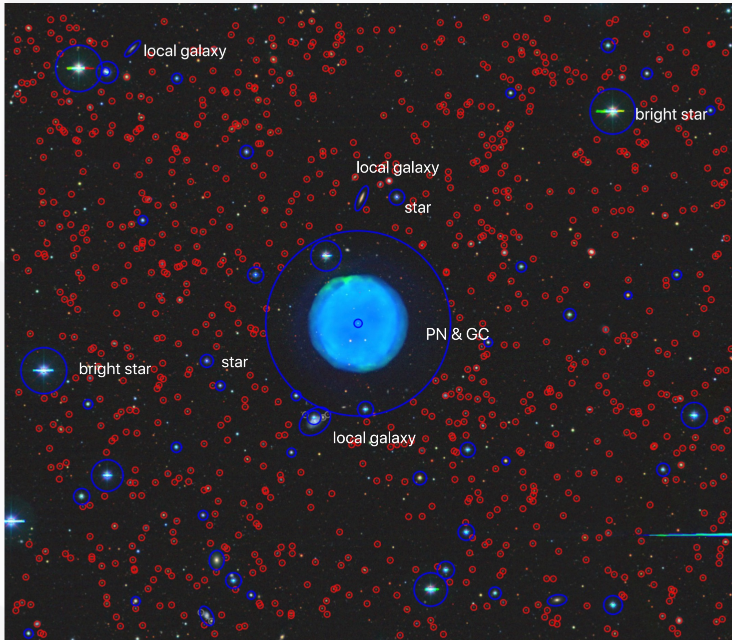
- **Simulation IO**: *Subhalo catalog* — *9tian/Uchuu/Mill/ELUCID*
- **Light-cone build**: *Light-cone catalog* — *To build from simulation box* / *Or input a lightcone catalog*
- **SHAM/HOD/CLF**: *Galaxy catalog* — *Assign luminosity…*
- **Galaxy properties**: assign properties — *multi-bands photometry* / *stellar mass, images*
- **Selection effect**: Observed catalog — *Geometry, flux limit,* / *foreground mask*

Foreground sources in DR9 for masking

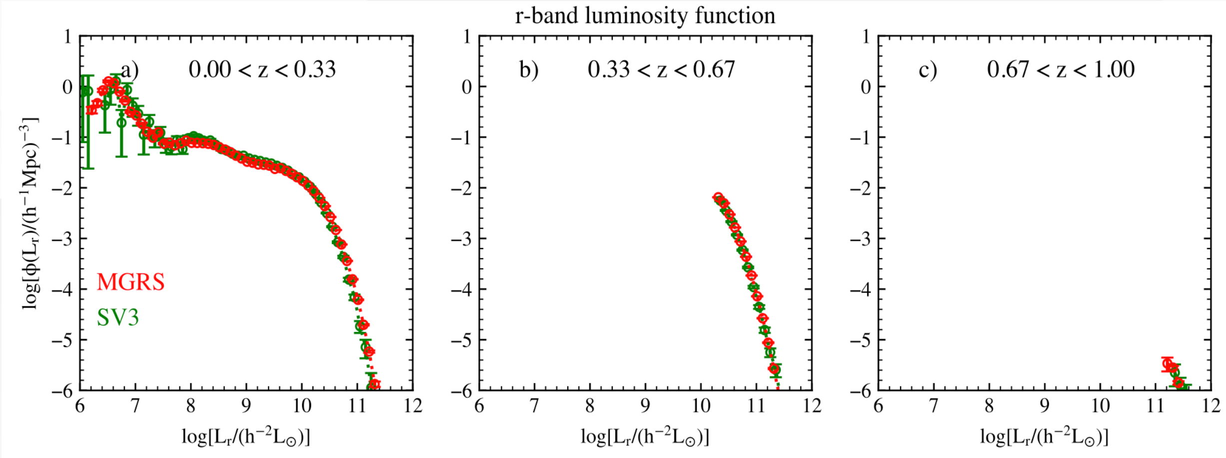
1. Bright Star
   773,673 Gaia DR2 [G_Gaia < 13]
   3,349 Tycho-2 [MAG_VT < 13]
2. Medium star
   13 < G_Gaia < 16
3. Globular Clusters & Planetary Nebulae
4. Local galaxy

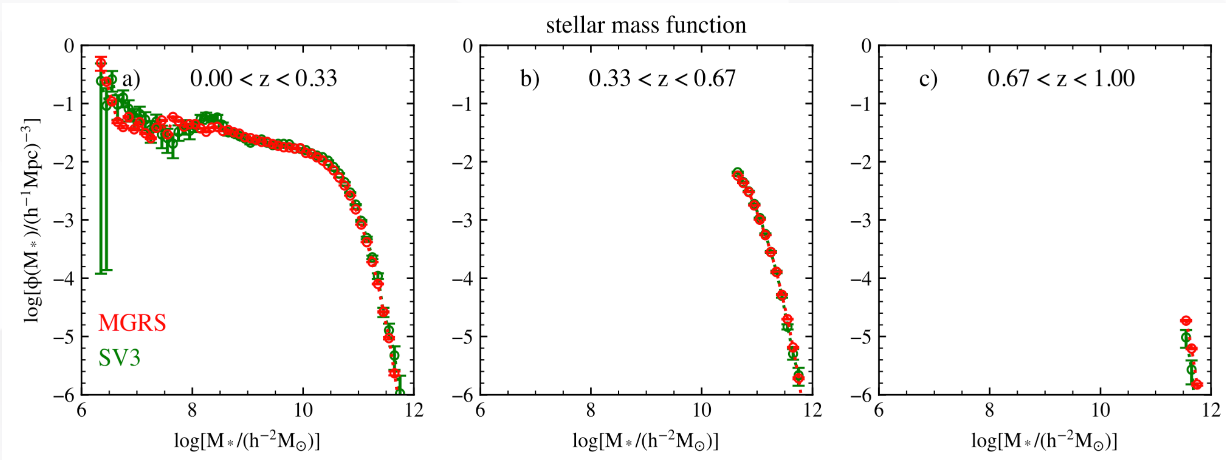
```
                 masked/   total [deg^2]
lsdr9-ngc    ---  476.78/9621.98 [deg^2]
lsdr9-sgc    ---  452.70/8601.19 [deg^2]
lsdr9-2tail  ---    8.67/ 127.10 [deg^2]
```

An example of foreground masking using LS dr9 imaging



Tests: r-band LFs & MFs





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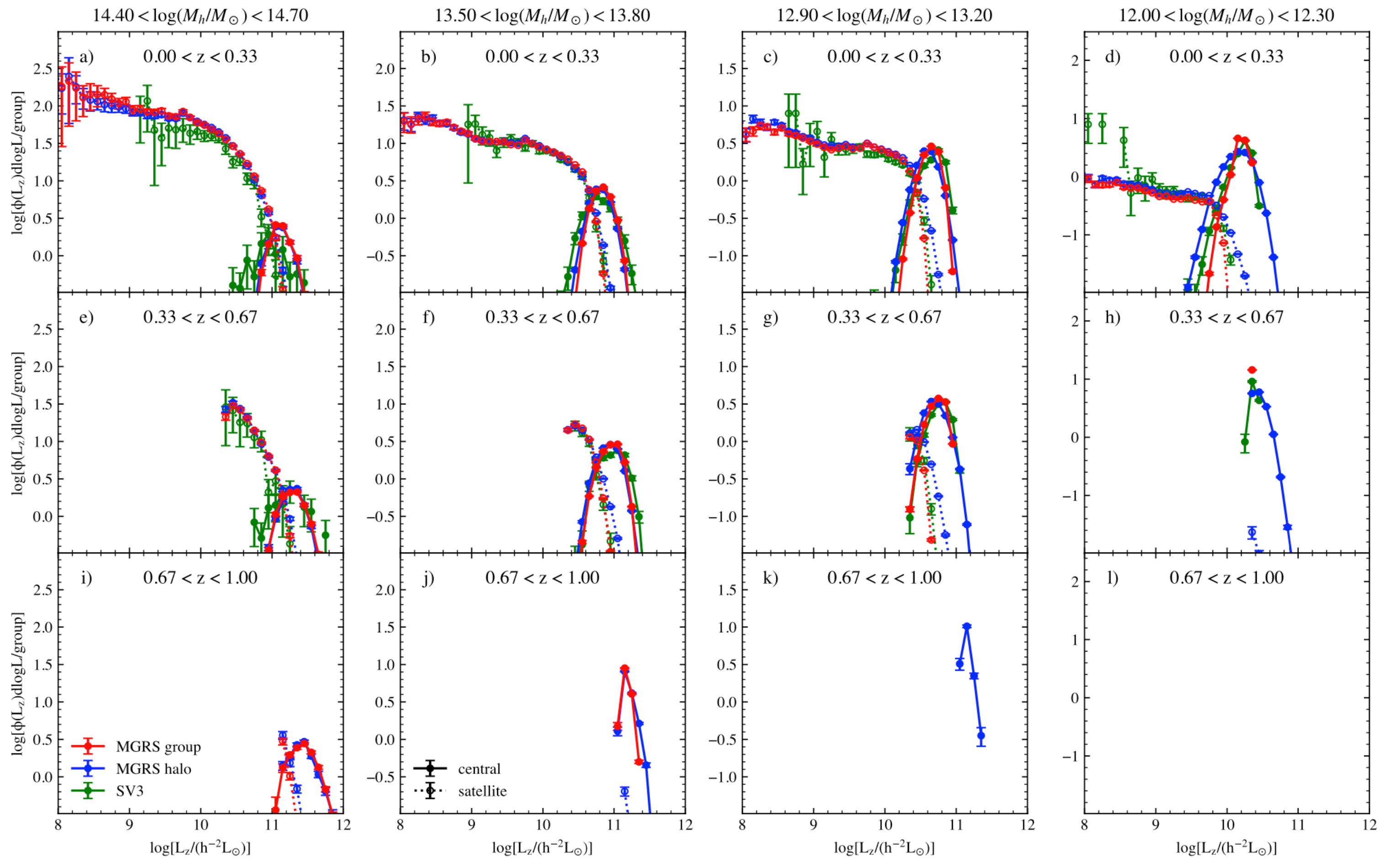
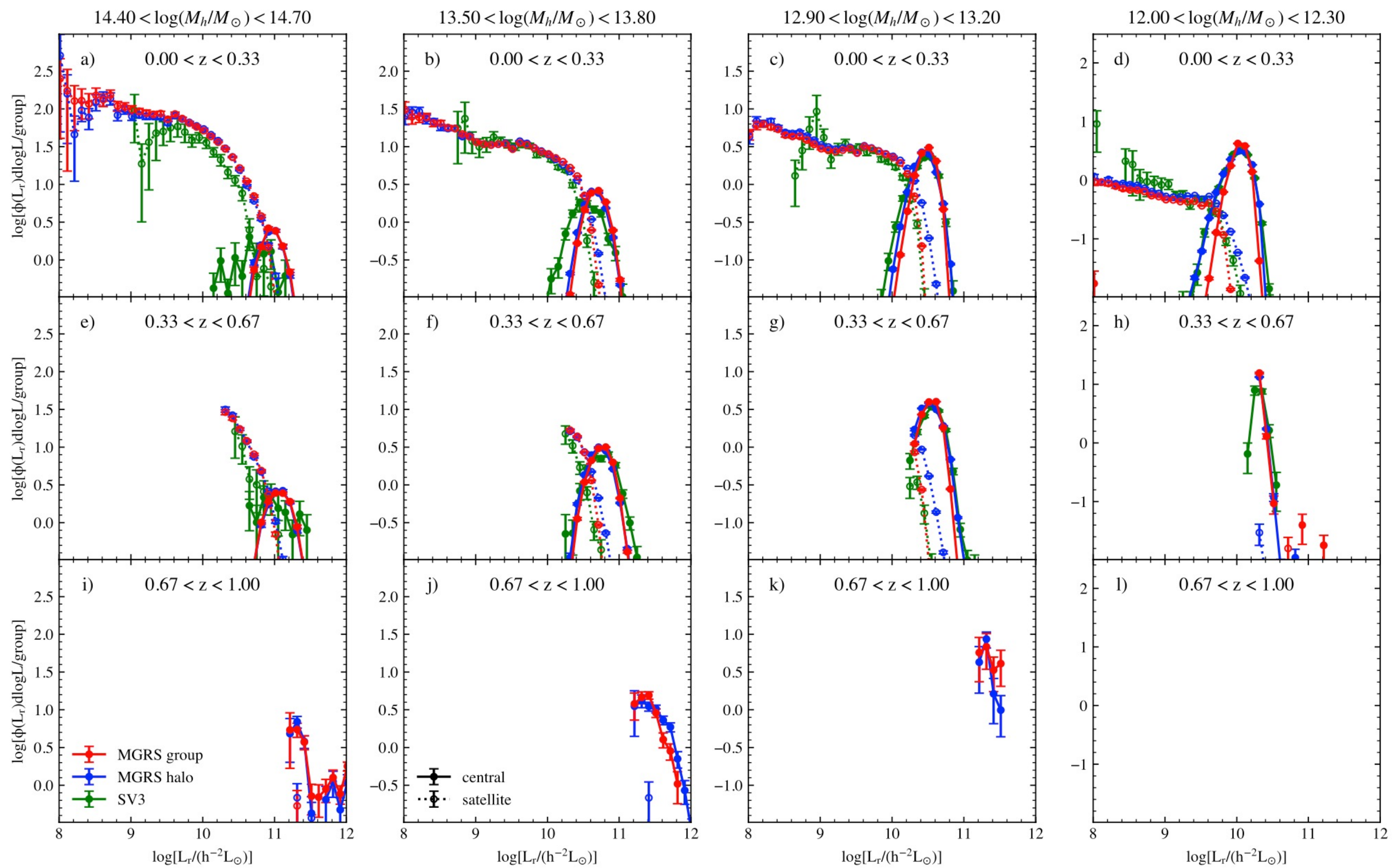
Tests: z-band CLFs of mock catalog



Tests: r-band CLFs of mock catalog



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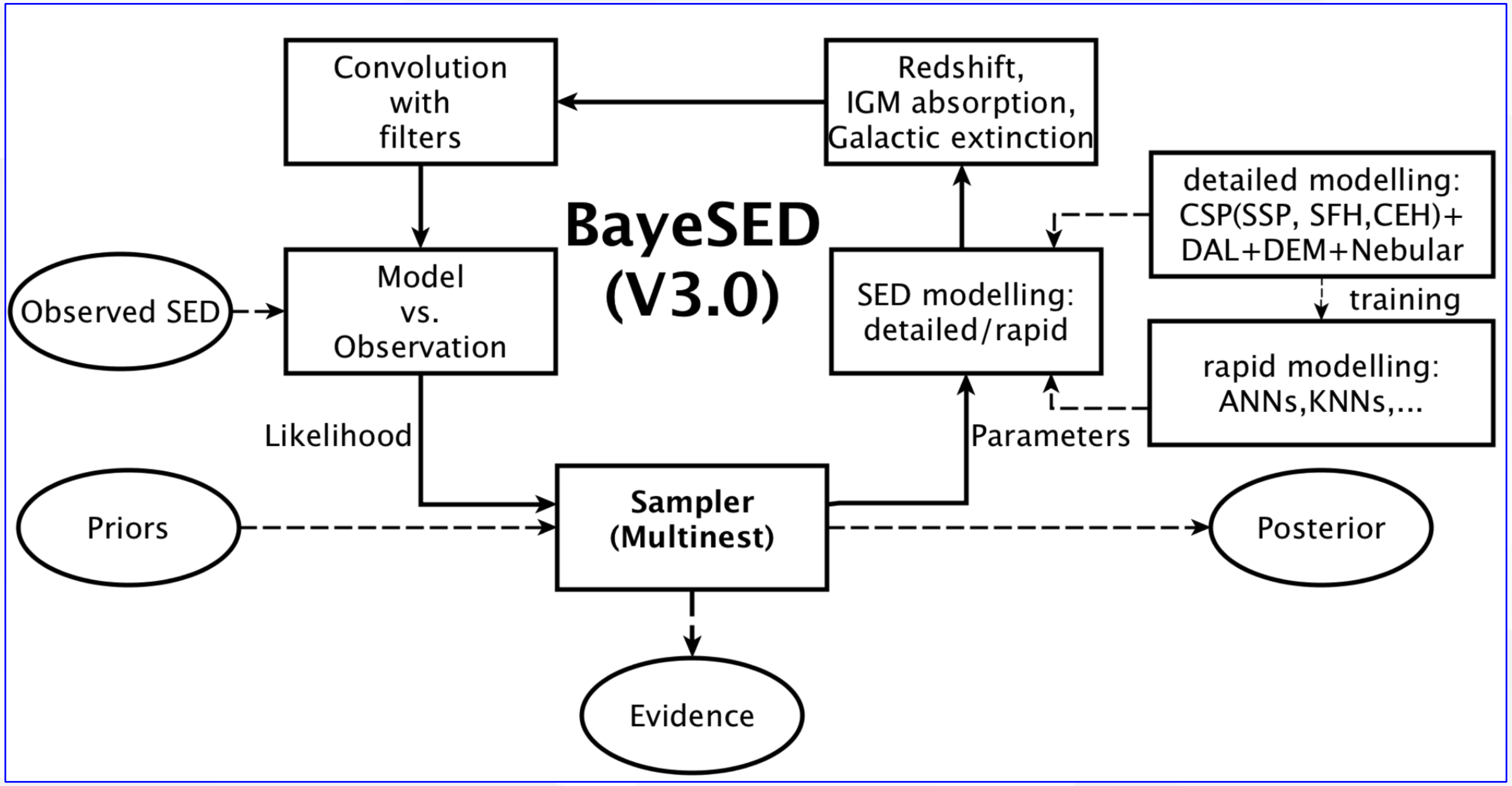
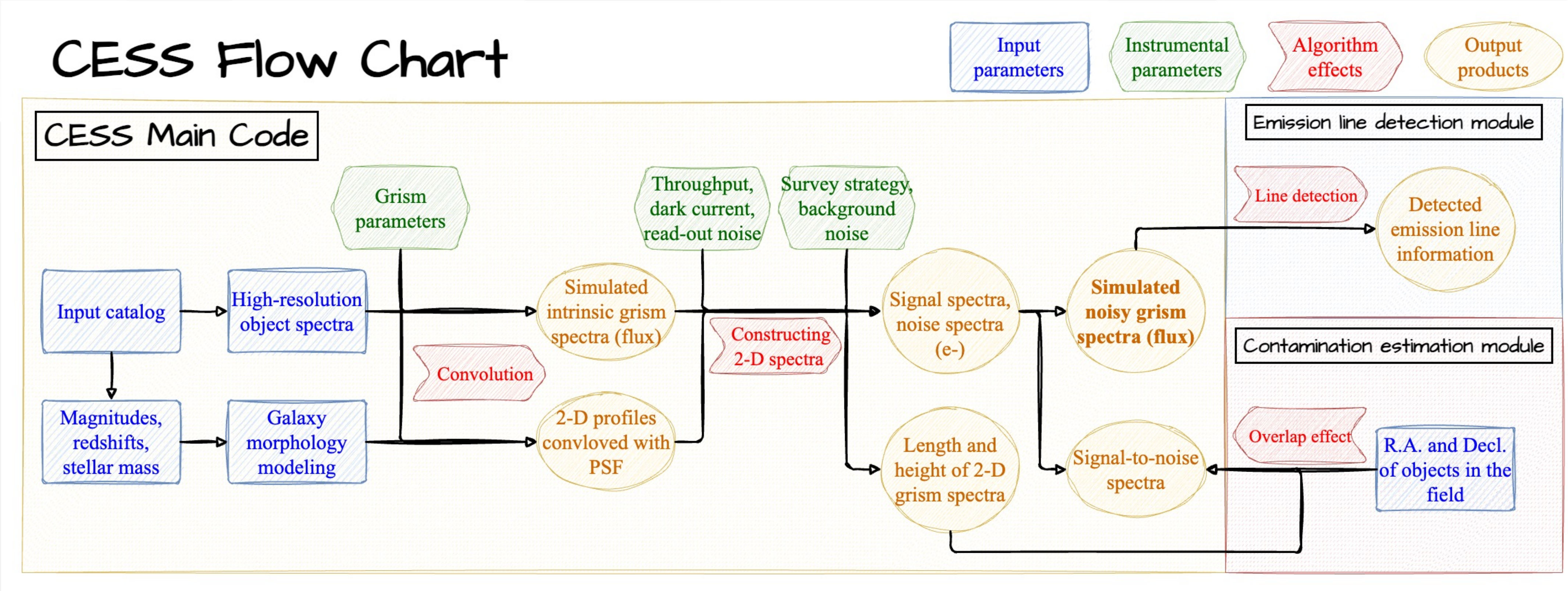
Task 2: Generating 1d spectrum for each galaxy



for 138 Million galaxies in our DESI LS DR9 seed catalog

Han et al. 2023

Task 3: Generating CSST slitless spectrum



CSST Emulator for Slitless Spectroscopy （CESS）

Wen et al. 2023, MNRAS submitted

Instrumental parameters

1. Downgrade to CSST slitless spectra resolution $\Delta\lambda$
   - convolved with a 1-D Gaussian kernel with FWHM=$\Delta\lambda$ (R ~ 200)
2. sky background count rate

$$B_{\rm sky} = A_{\rm eff} \int \tau_\lambda \frac{\lambda}{hc} l_{\rm p}^2 I_{\rm sky} d\lambda,$$

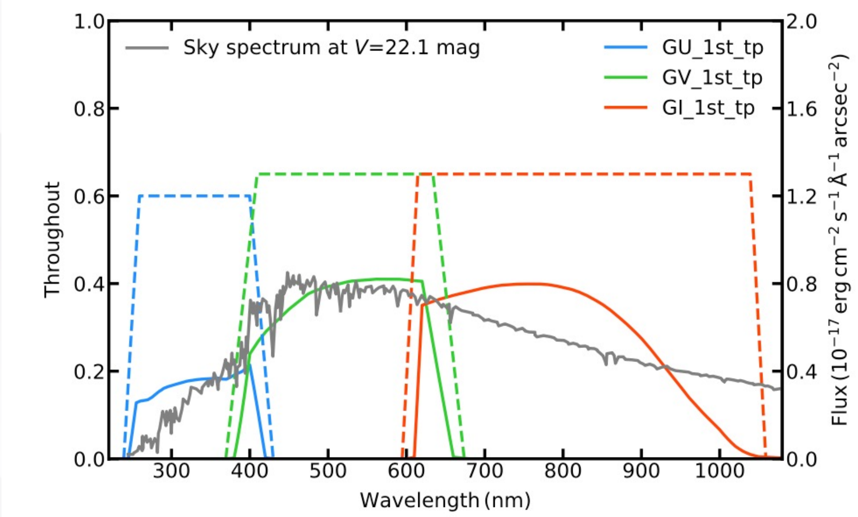
3. Noise estimation (e^- count rate and SNR)
   - count rate in a spectral resolution $\Delta\lambda$

$$C = A_{\rm eff} \int_{\lambda_{\rm min}}^{\lambda_{\rm max}} \tau_\lambda \frac{\lambda}{hc} F_\lambda d\lambda,$$

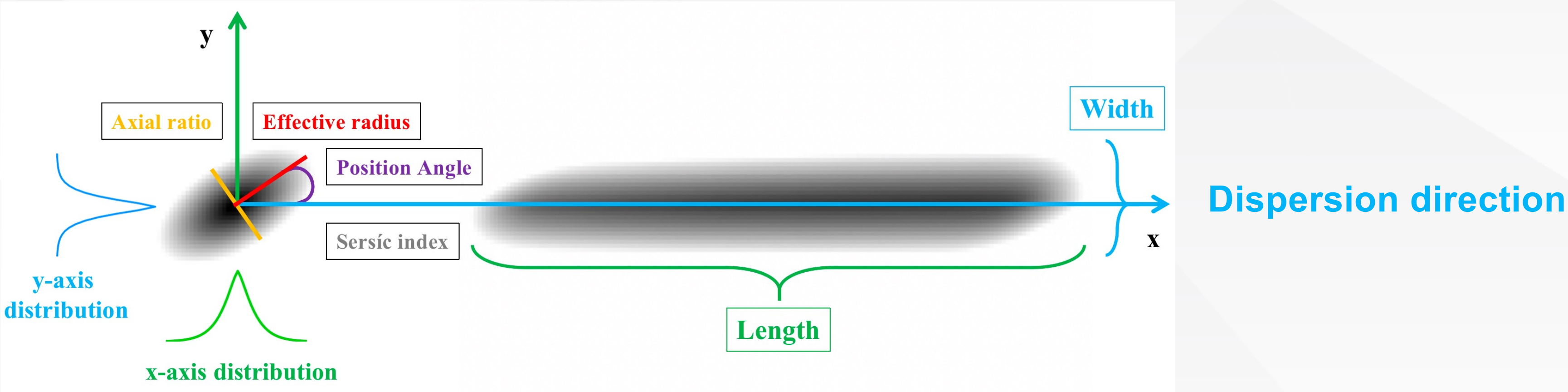
   - SNR in the spectral resolution $\Delta\lambda$

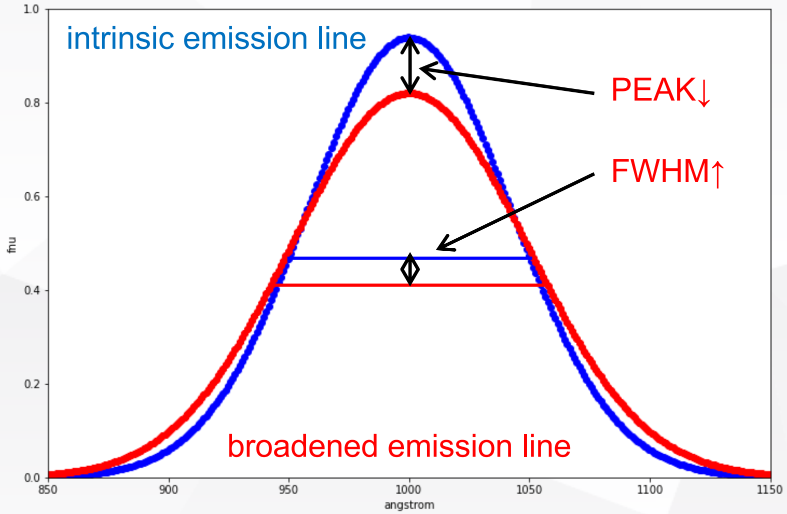
$$\mathrm{SNR} = \frac{C \times t}{\sqrt{C \times t + N_{\rm pix} \times (B_{\rm sky} + B_{\rm dark}) \times t + N_{\rm pix} \times N_{\rm read} \times R_{\rm n}^2}}$$

Gratings of CSST	*GU*	*GV*	*GI*
Survey area (deg^2)		17500	
Exposures		150 s × 4	
Point spread function		$R_{\rm EE80} \lesssim 0''.3$	
Wavelength Coverage (nm)	255 – 420	400 – 650	620 – 1000
Spectral Resolution [$\lambda/(\Delta\lambda)$]	241	263	270
5σ-depth (mag)	23.2	23.4	23.2
0th to 1st spectrum separation (mm)	4.22	5.60	5.44

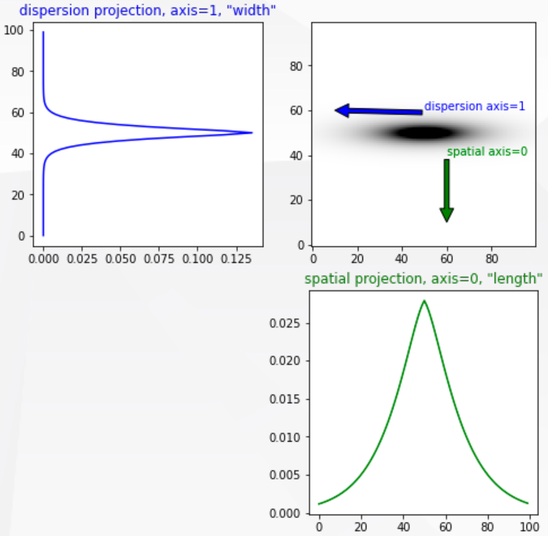


The self-broadening effects



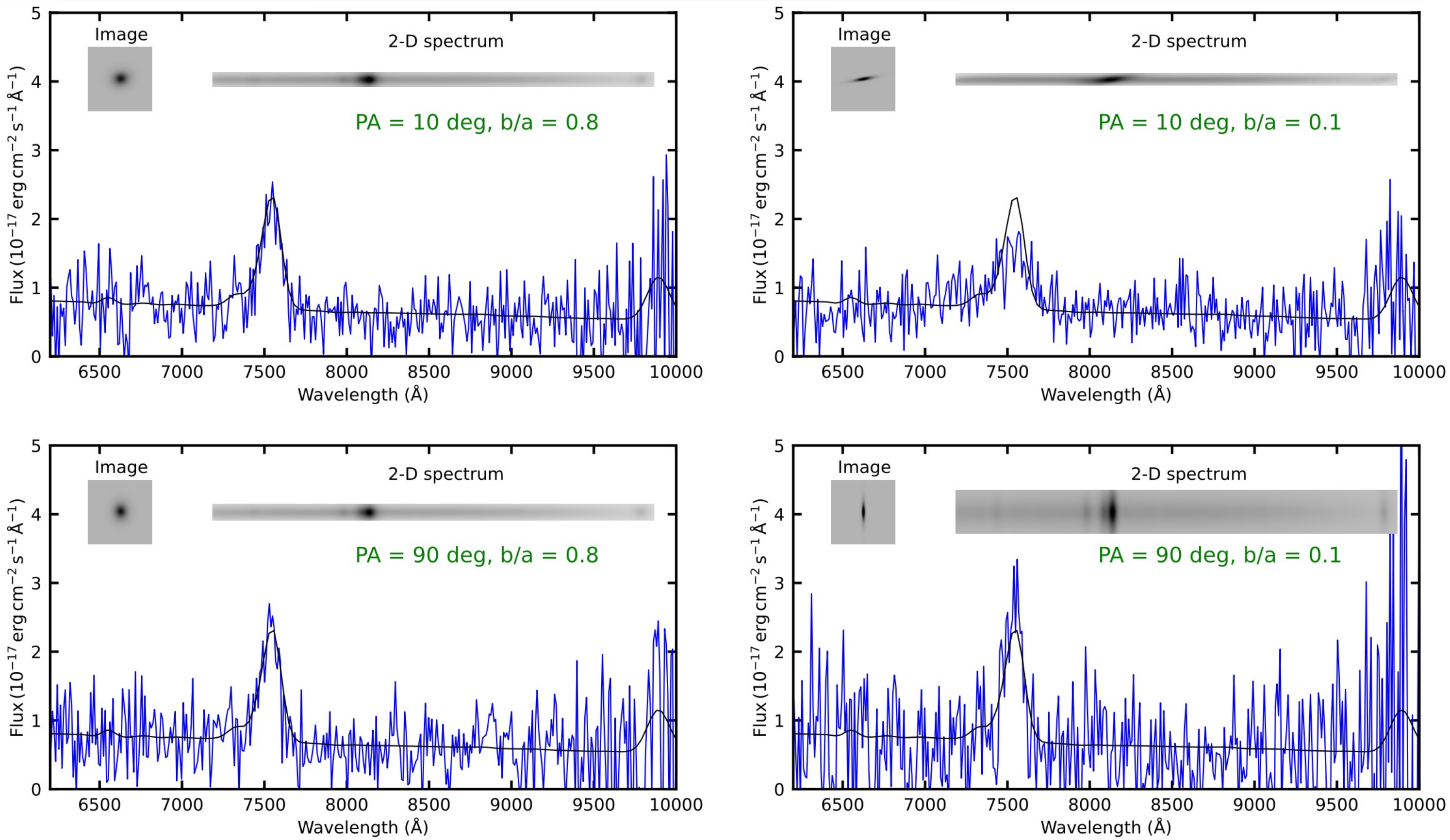


Effects on extracted 1-D Slitless Spectrum



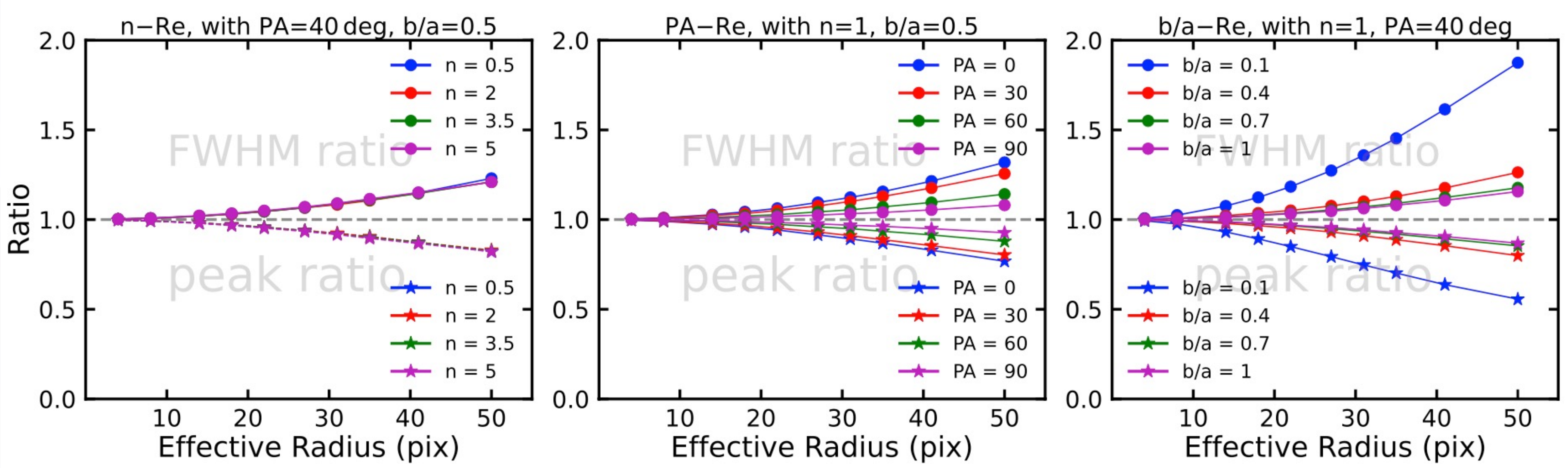
spatial projection -- "length":
self-blending effect, affect the shape of spectrum.
dispersion projection -- "width":
the spectrum extraction box, affect the noise level in each spectral resolution unit.

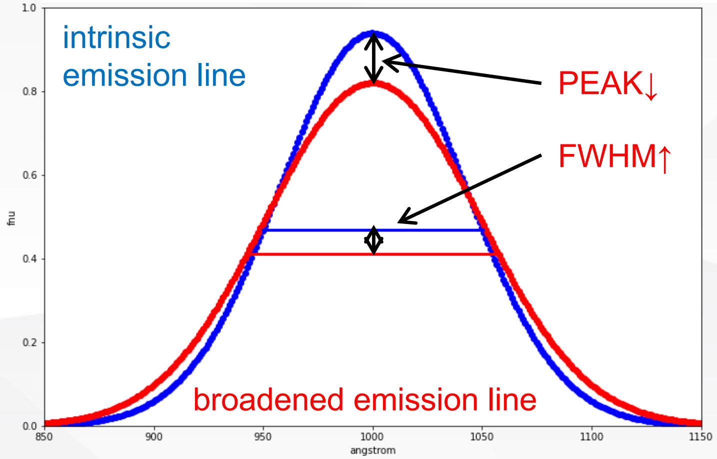
larger "length", broadened spectra



larger "width", larger noise

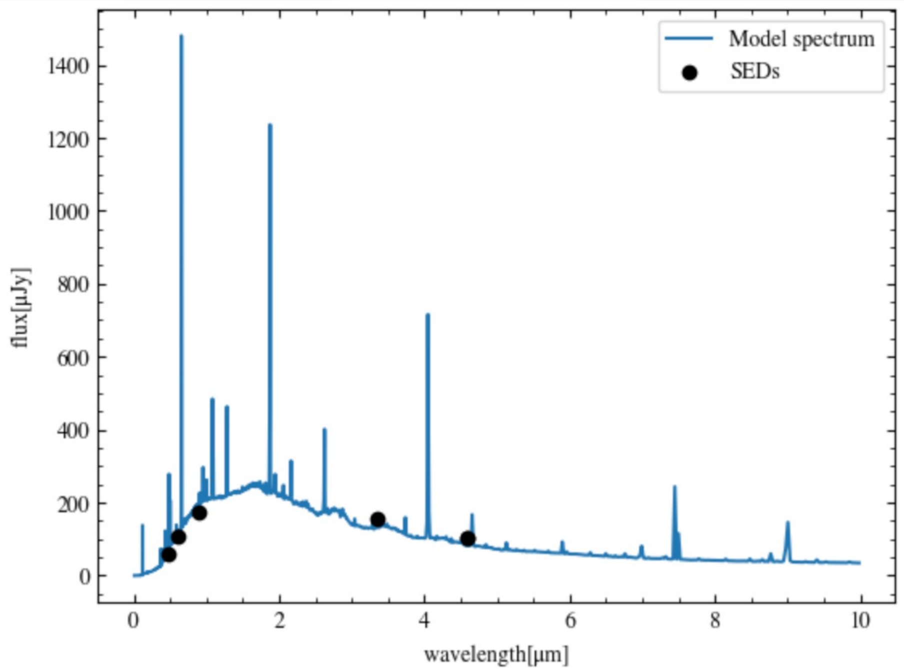
Morphological dependence





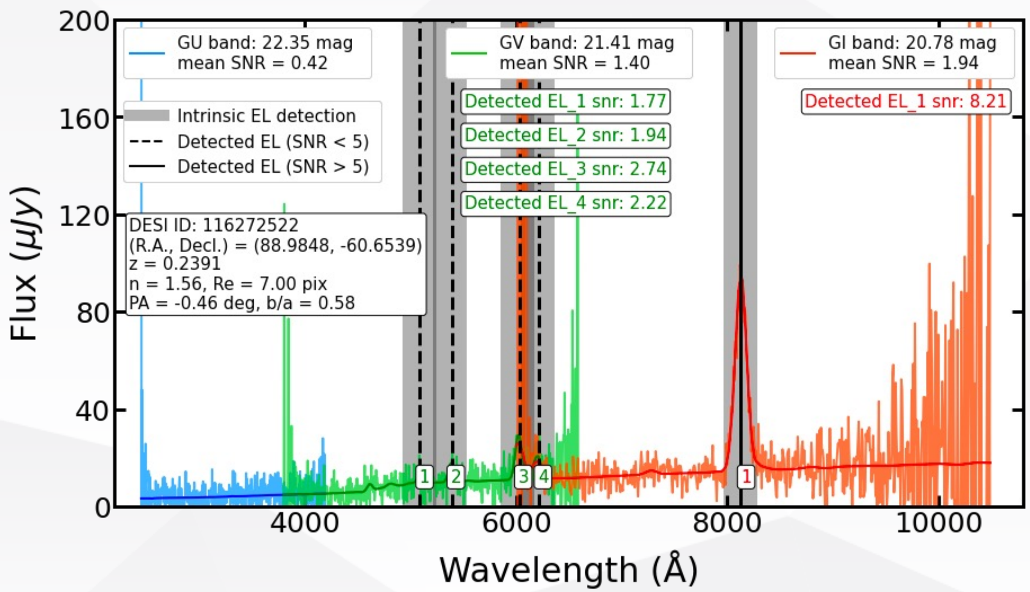
1. The Re is the dominant morphological parameter and the impact begins to be significant at Re ≤1.1 arcsec.
2. Sérsic index has little or no effect on broadening the spectral features.
3. PA and b/a alone play a secondary role but may magnify the broadening effect.

Application - model spectra from DESI LS DR9



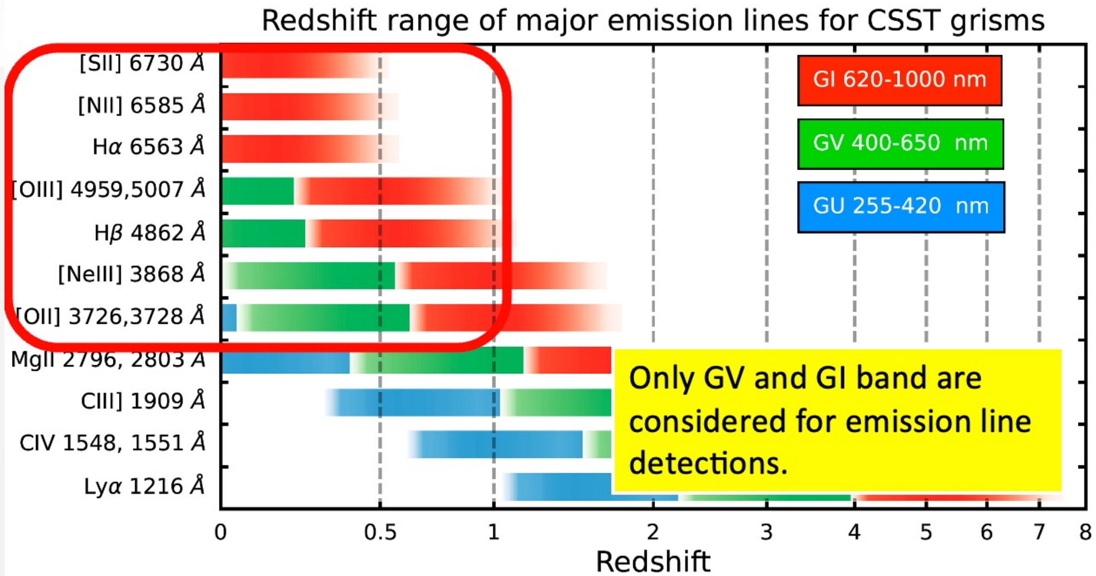
Intrinsic spectra are generated from the best fitting of 5-band SEDs (BayeSED; Han et al. 2023).

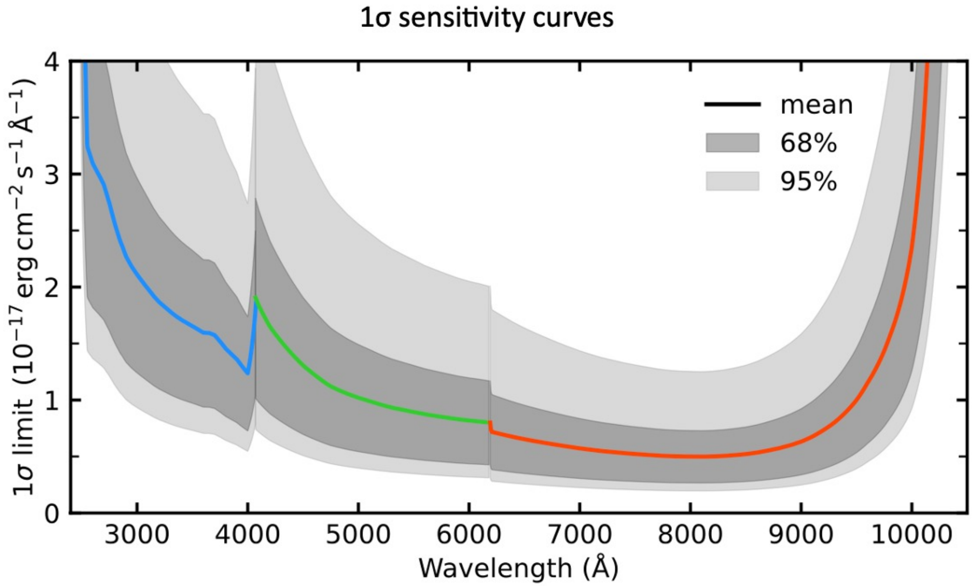
An example of emulator output spectrum



We generate a galaxy spectrum library with known parameters, including best-fitting spectra, redshift, sky coordinates, and physical parameters. In total, this seed galaxy spectrum library contains 138,348,981 galaxies.

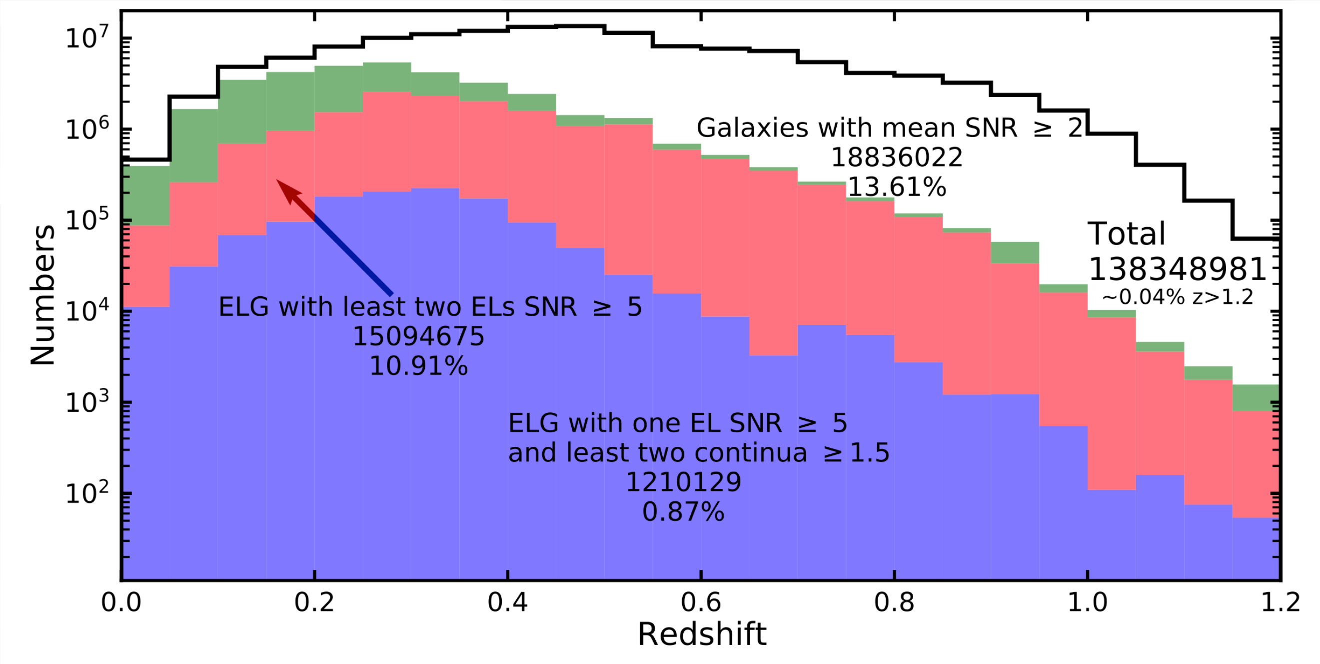
Emission Line Detection





The mean 1σ noise level reaches about 1.5, 1, and 0.5 × 10^{-17} erg s^{-1} cm^{-2} Å^{-1} for GU, GV, and GI, respectively.

Secure redshift percentage

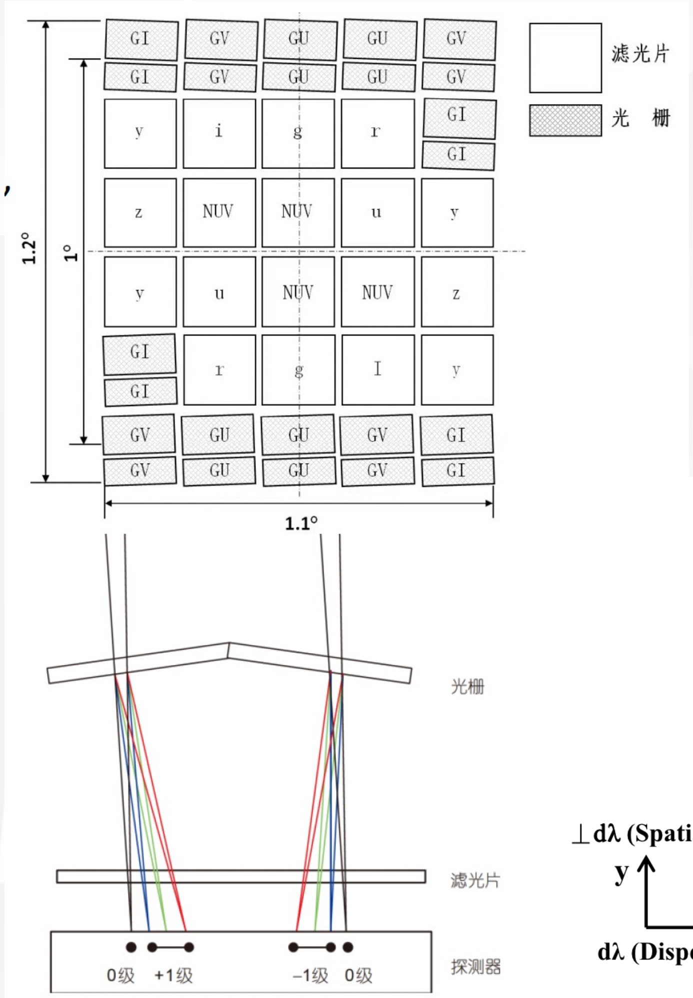


~25.39% of the sample has secure redshift measurements.

Criteria for Secure redshift measurements:

- ELGs with one emission line of SNR ≥ 5 and at least two band continua of SNR ≥ 1.5 (blue),
- ELGs with at least two emission lines of SNR ≥ 5 (red),
- Other galaxies with at least two band continua of SNR ≥ 2 (green).

Module for contamination

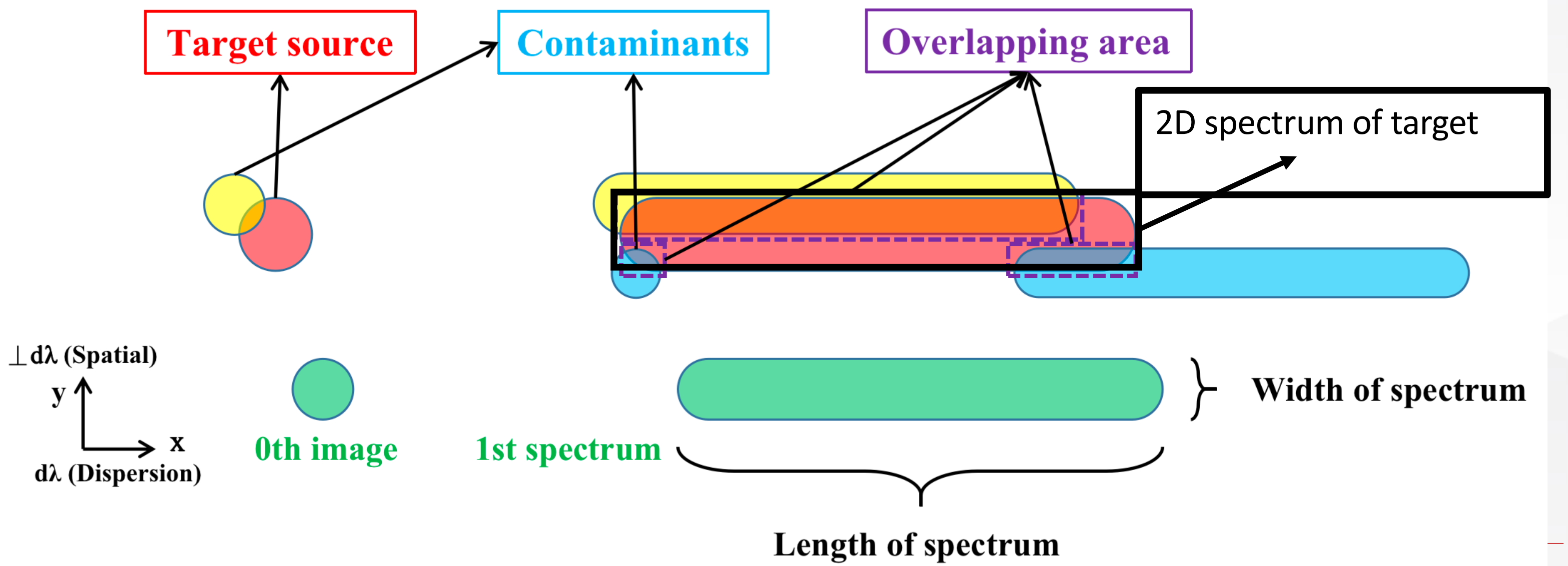


The simulated zero- and first-order slitless image:

1. Knowing the electron spectrum of each source, pixels area covered by each spectrum on the CCD (from R.A., Decl., spectrum length and height), recovering the entire field on the CCD.

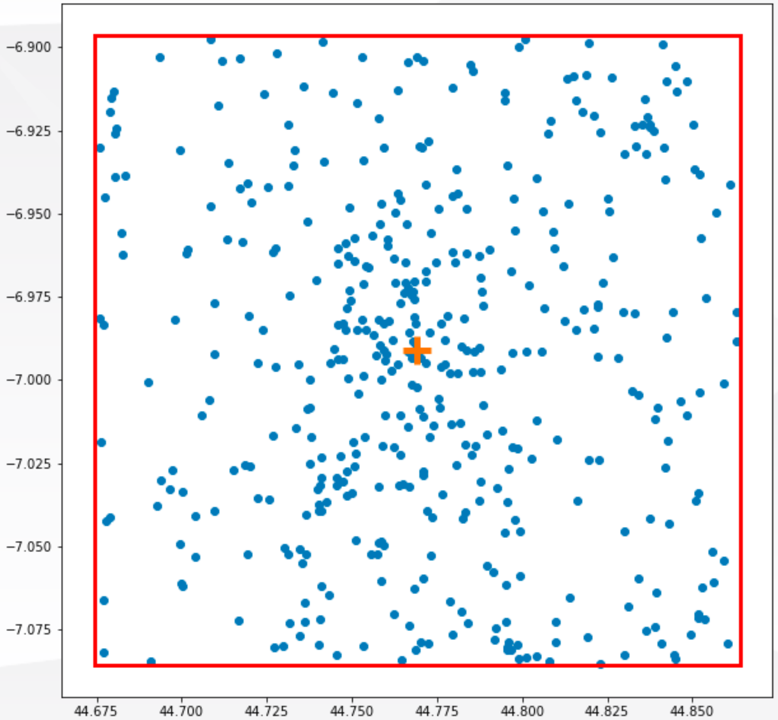
2. In the extraction area of the target source, treat all non-object electrons as noise, calculate the noisy flux proportion.

The contamination fractions are calculated as follows:



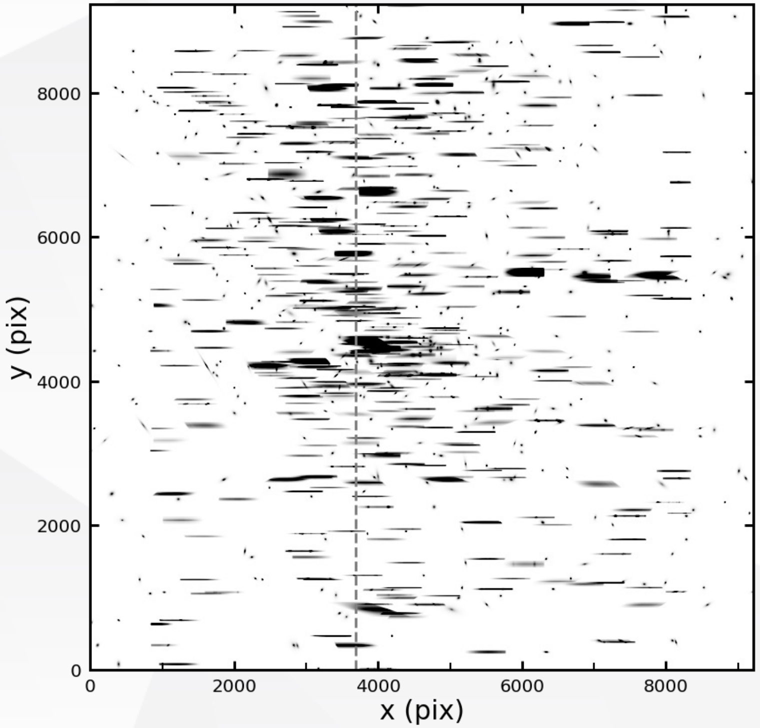
An example of the simulated zero- and first-order slitless image

R.A., Decl.: 44.76918152, -6.99106257,
zphot:0.439, richness:119.745
DESI cluster info from Zou et al. 2021



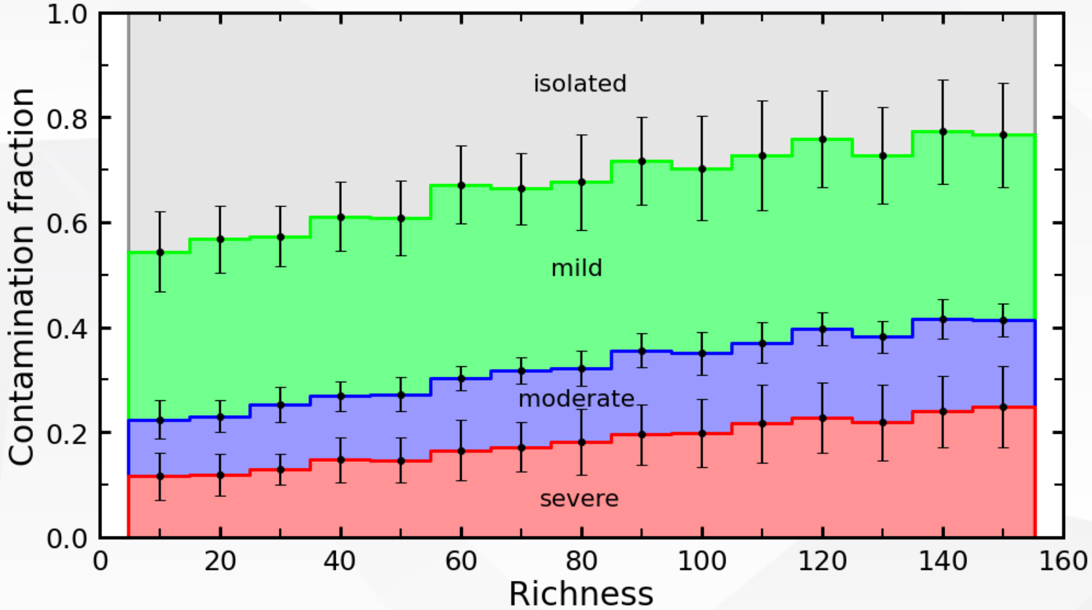
CESS

Reconstructed 0th and 1st
slitless spectrum map (without noise)

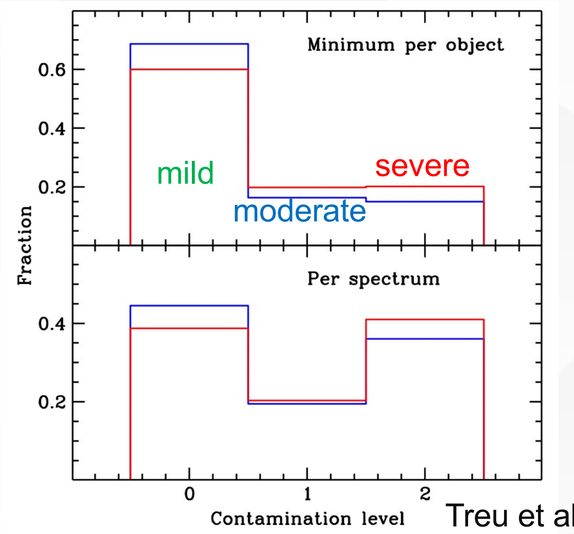


Contamination fraction in Clusters

Sampling 1500 clusters with different richness.



Contamination statistics for MACS J0717.5+3745:
A cluster case of HST grism (G102, blue; G141, red)



Treu et al. 2015

- The overlap rate rises from 0.55 to 0.8.
- **The contamination fraction increases:**
  1. 10% to 25% for the severe case (severe level: > 40%)
  2. 10% to 15% for the moderate case (moderate level: 10% ~ 40%)
  3. remains nearly constant at about 35% for the mild case (mild level: < 10%)
  4. --to ba applied to the seed galaxy and group catalog Yang et al. 2021

Contamination level classification:
mild: < 10%
moderate: 10% ~ 40%
severe: > 40%

Conclusion

- Using Jiutian simulation and DESI observational data, we build the MGRSs as the benchmark for the studies of various CSST observation selection effects.
- Standard SHAM and 3-param sampling work fairly well in terms of LFs, SMFs, and CLFs.
- We developed the CSST Emulator for Slitless Spectroscopy (CESS), which is not dependent on Grizli.
- The Re is the dominant morphological parameter of the self-deblending effects.
- We generate the simulated slitless spectra according to DESI LS DR9.
- Redshift completeness and contamination in clusters are explored.
- A lot more work is needed...

Future work

- CSST large scale structure analysis pipeline: I. constructing reference mock redshift surveys (led by: Yizhou Gu, Xiaohu Yang, Qingyang Li, et al.)
- CSST large scale structure analysis pipeline: II. slitless spectra emulator (led by: Ren Wen, Xianzhong Zheng, Hu Zou, et al.)
- CSST large scale structure analysis pipeline: III. redshift measurements (led by: Xianzhong Zheng, Hu Zou, et al.)
- CSST large scale structure analysis pipeline: IV. 2PCF analysis tools (led by: Feng Shi, Hong Guo, et al.)
- CSST large scale structure analysis pipeline: V. selection effects (led by: Yizhou Gu)
- CSST large scale structure analysis pipeline: VI. image systematics (led by: Haojie Xu et al.)
- CSST large scale structure analysis pipeline: VII. HOD applications (led by: Hong Guo, et al.)
- CSST large scale structure analysis pipeline: VIII. CLF applications (led by: Xiaoju Xu, Jiaqi Wang, et al.)
- CSST large scale structure analysis pipeline: IX. cosmological applications (led by: Zhongxu Zhai, et al.)
- CSST large scale structure analysis pipeline: X. cross correlations with CMB (led by: Pengjie Zhang, et al.)

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Thank you!

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