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China-VO

基于多模态算法的发射线星系测光红移估计

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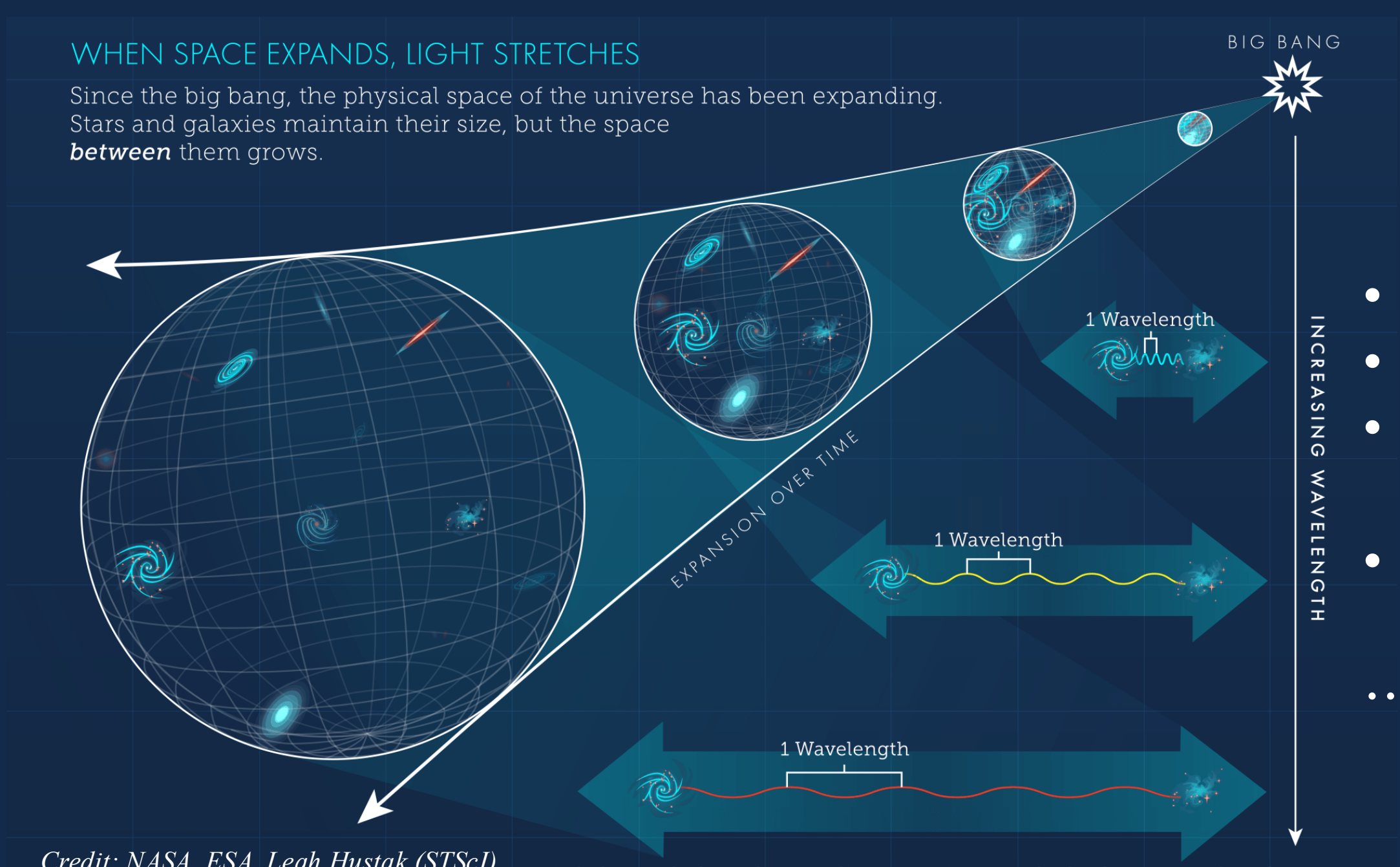
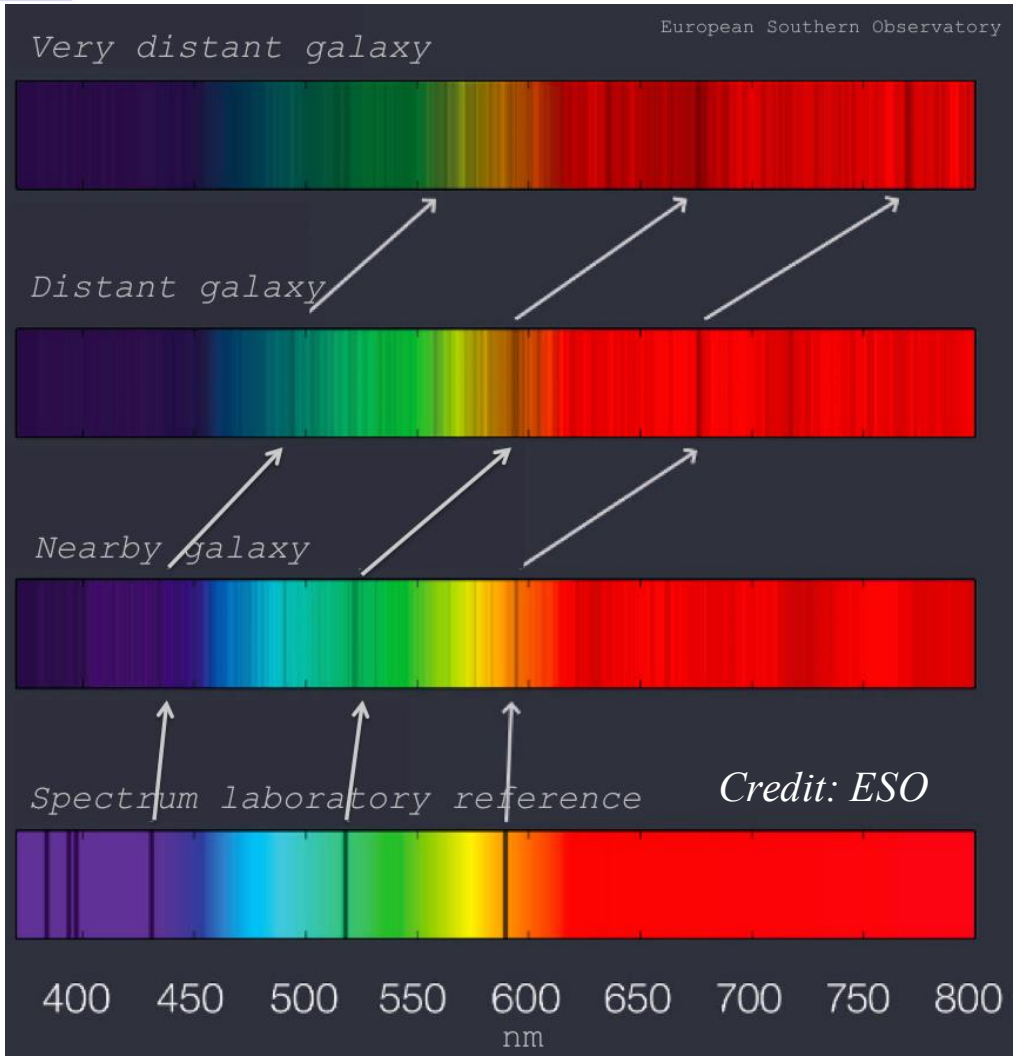
国家天文科学数据中心

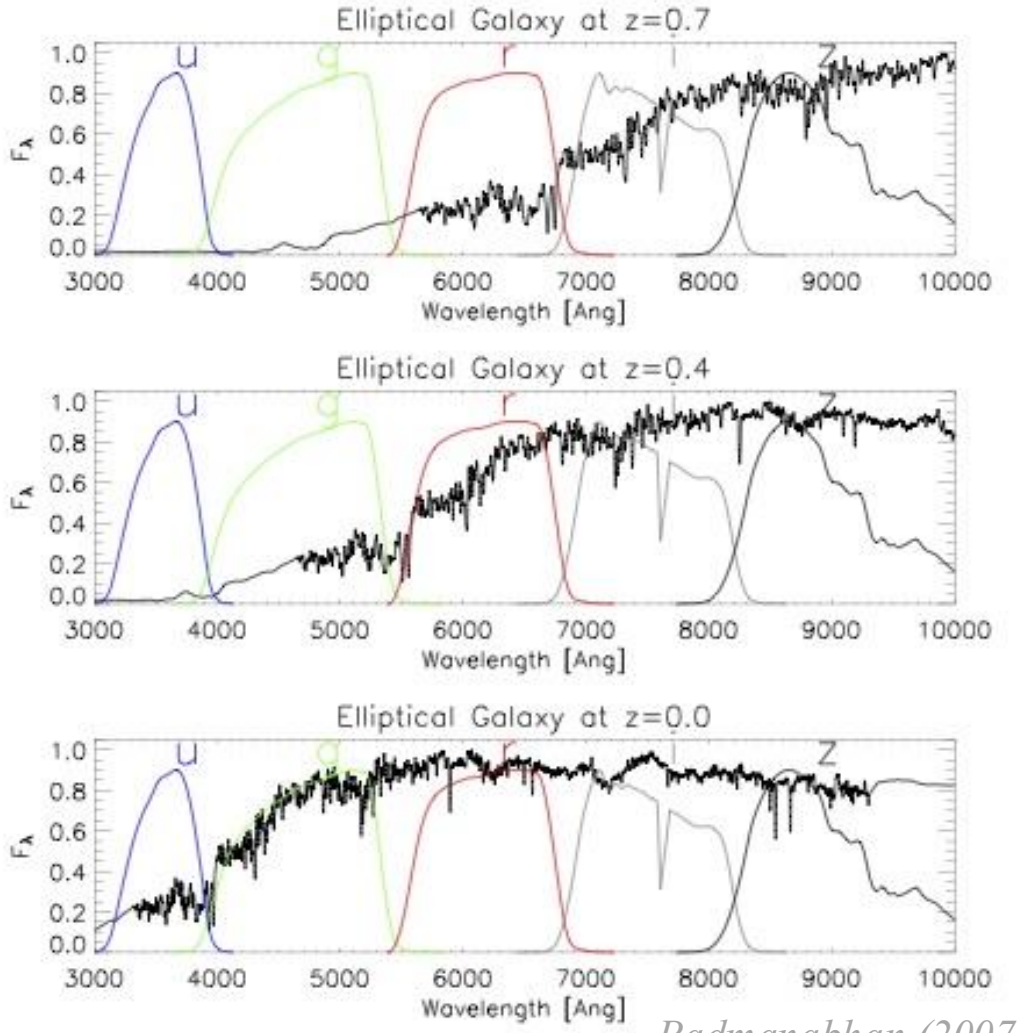


红移

- 天体距离
- 星系演化
- 暗物质与暗能量
- 宇宙大尺度结构
- …

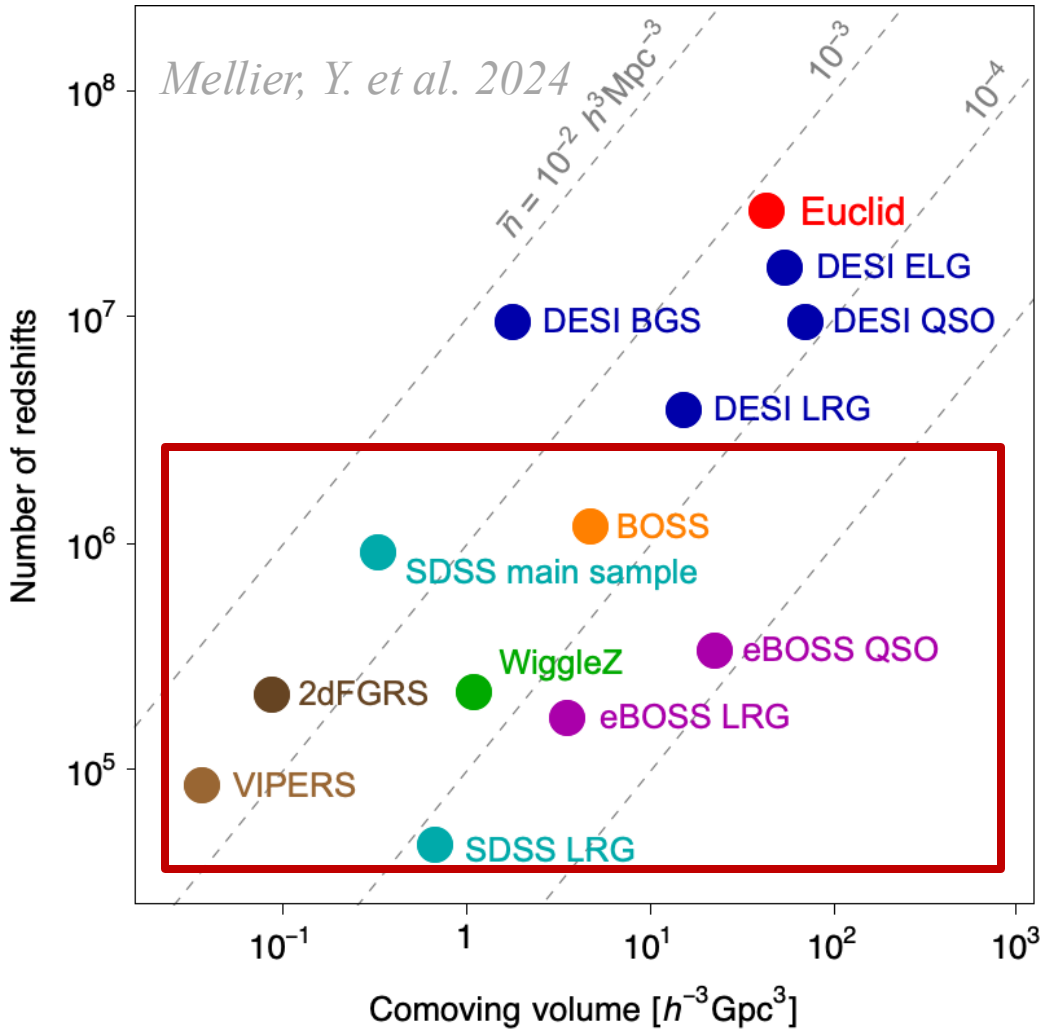
光谱红移与测光红移





Padmanabhan (2007)

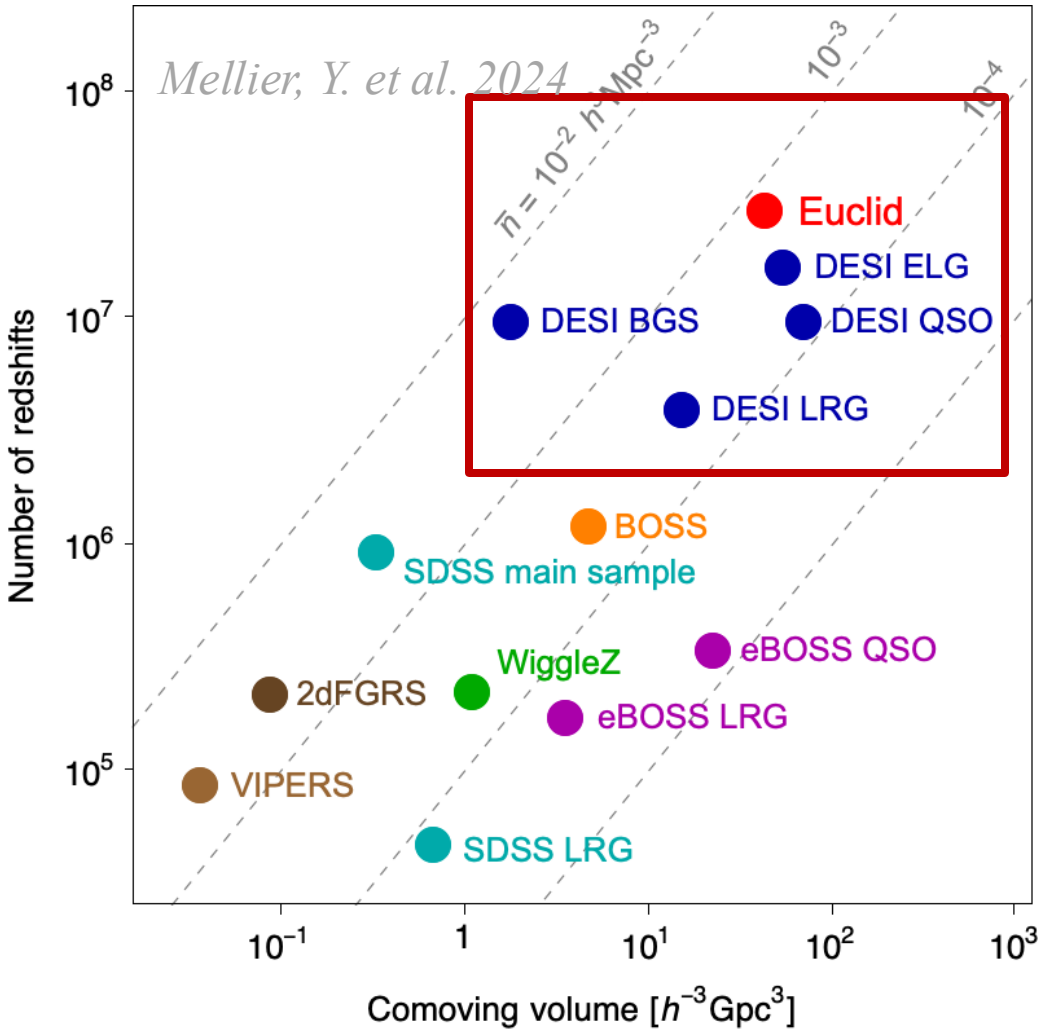
光谱红移巡天

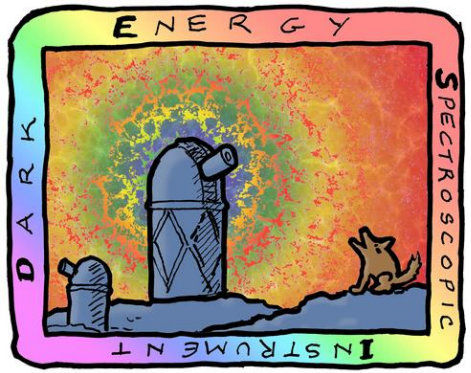


1997-2003
z<0.2

2000-2021(DR17)
z < 1
Galaxy & QSO

光谱红移巡天

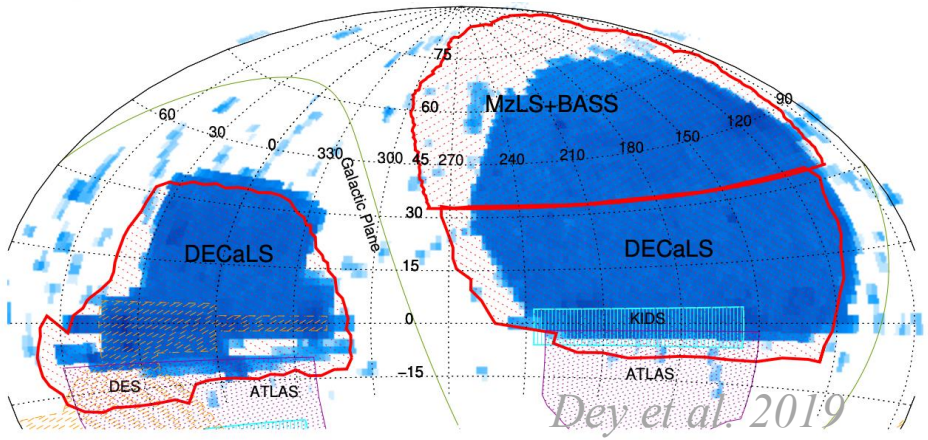




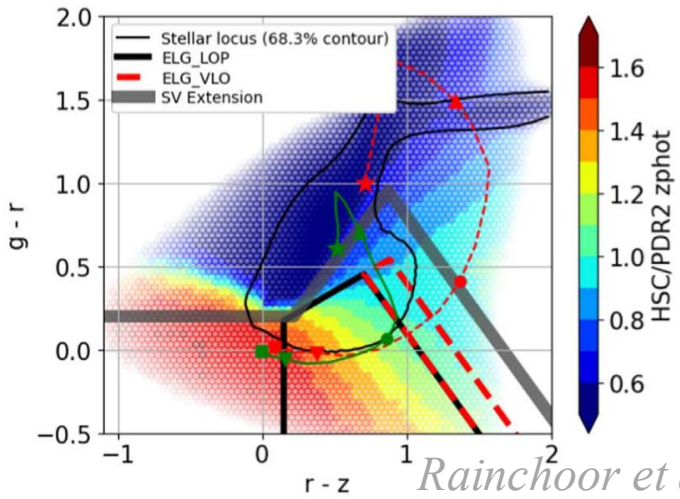
2021 -
z ~ 0 - 4
4千万

2024 -
5千万

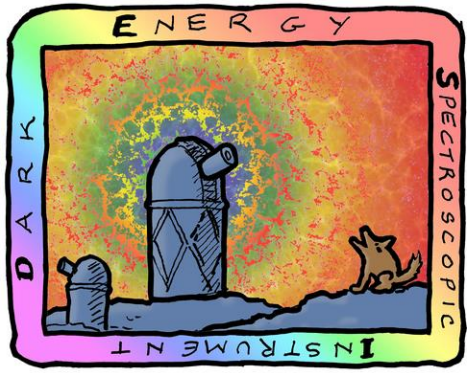
Dark Energy Spectroscopic Instrument



Dey et al. 2019



Rainchoor et al. 2023



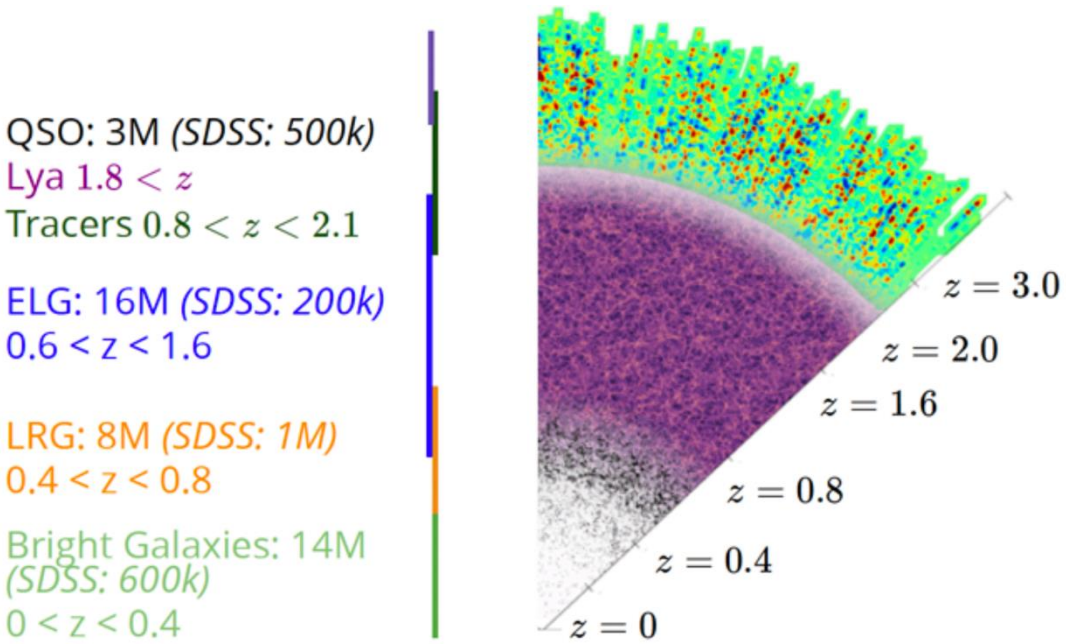
DESI Legacy Imaging Surveys 选源 观测

Suvey Validation	DESI - 5 year project					
2020	2021	2022	2023	2024	2025	2026

测光 DR9 DR10（28亿）

光谱 EDR (180万) DR1 (1870万)

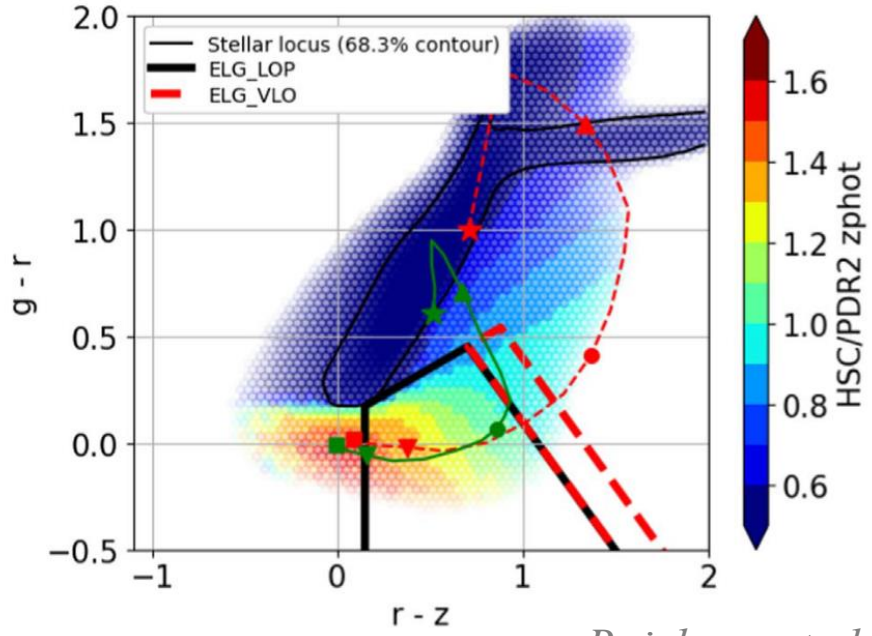
发射线星系



Credit: Pauline Zarrouk

ELG对于理解星系形成演化、化学成分以及宇宙大尺度结构至关重要

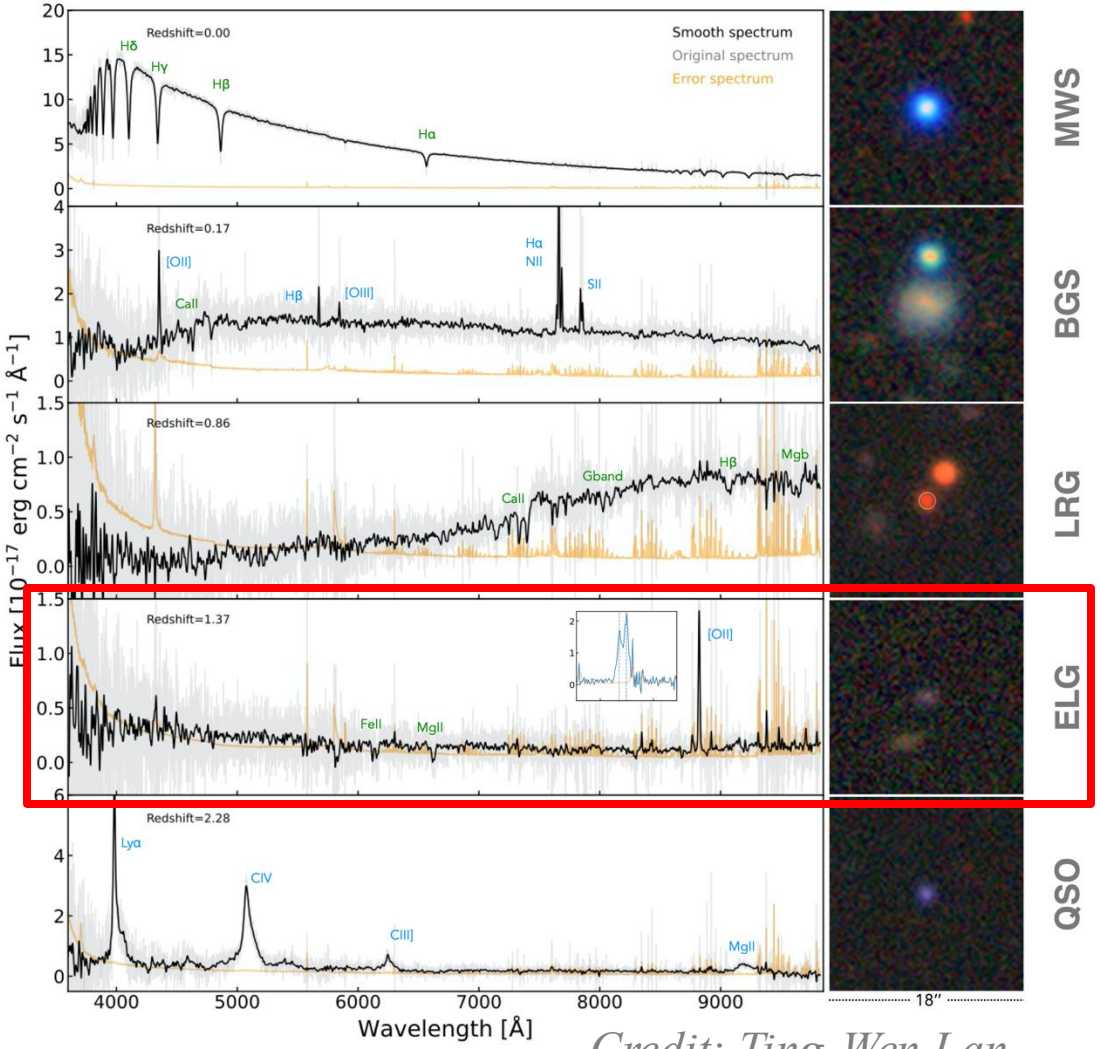
提升ELGs的**测光红移**预测准确性有助于光谱**观测选源**



Raichoor et al. 2023

- ✓ 观测目标的成功率
- ✓ 选源的完备性
- ✓ 减少非ELG的污染

发射线星系



Credit: Ting-Wen Lan

Table 12. The performance comparison of our models with different samples from DESI EDR to the work of Zhou et al. (2023).

Sample	Method	$\sigma_{\rm NMAD}$	$\sigma_{\rm NMAD}(z<21{\rm mag})$	$O(0.10)(\%)$	$O(0.10)(z<21{\rm mag})(\%)$
DESI SV1 BGS	Zhou et al. (2023)	0.021	0.021	2.0	2.0
	Our work	**0.013**	**0.013**	**0.3**	**0.3**
DESI SV1 LRG	Zhou et al. (2023)	0.028	0.025	3.3	2.7
	Our work	**0.019**	**0.017**	**3.4**	**2.6**
DESI SV1 ELG	Zhou et al. (2023)	0.095	0.041	34.7	14.4
	Our work	**0.073**	**0.038**	**28.3**	**13.4**
DESI SV3 BGS	Zhou et al. (2023)	0.019	0.019	1.3	1.3
	Our work	**0.012**	**0.012**	**0.2**	**0.2**
DESI SV3 LRG	Zhou et al. (2023)	0.025	0.024	1.9	1.6
	Our work	**0.012**	**0.012**	**0.9**	**0.8**

Credit: Li et al. 2024

Targets	BGS				LRG			
Metrics	η	$\sigma_{\rm NMAD}$	$\overline{\Delta z}$	$N_{\rm training}$	η	$\sigma_{\rm NMAD}$	$\overline{\Delta z}$	$N_{\rm training}$
Our work (Separately)	0.14%	0.020	-0.0031	0.3 m	0.68%	0.030	0.0111	0.1 m
Our work (Bayesian)	0.14%	0.018	-0.0015	0.3 m	0.45%	0.026	0.0022	0.1 m
Our work (Collectively)	0.83%	0.029	0.0160	-	1.07%	0.033	0.0151	-
Zou et al. (2019)	0.19%	0.013	0.0	1.2 m	0.18%	0.016	0.0013	0.8 m
Targets	ELG				NON			
Metrics	η	$\sigma_{\rm NMAD}$	$\overline{\Delta z}$	$N_{\rm training}$	η	$\sigma_{\rm NMAD}$	$\overline{\Delta z}$	$N_{\rm training}$
Our work (Separately)	16.65%	0.112	0.0257	0.1 m	9.44%	0.058	0.0014	0.2 m
Our work (Bayesian)	16.07%	0.107	0.0184	0.1 m	7.87%	0.052	0.0140	0.2 m
Our work (Collectively)	15.78%	0.108	0.0154	-	8.15%	0.053	0.0304	-
Zou et al. (2019)	6.23%	0.053	0.0067	0.02 m	2.46%	0.024	0.0022	0.6 m

Credit: Zhou et al. 2024

多模态天文数据

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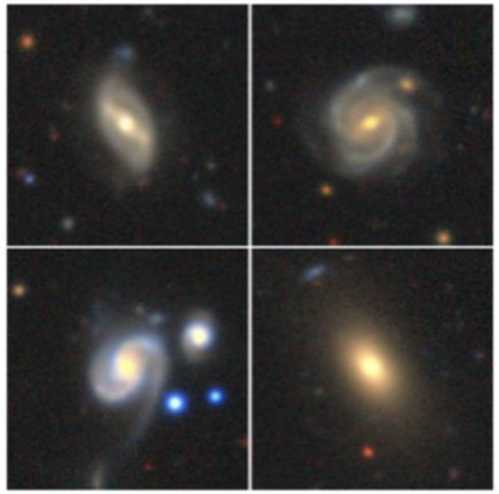
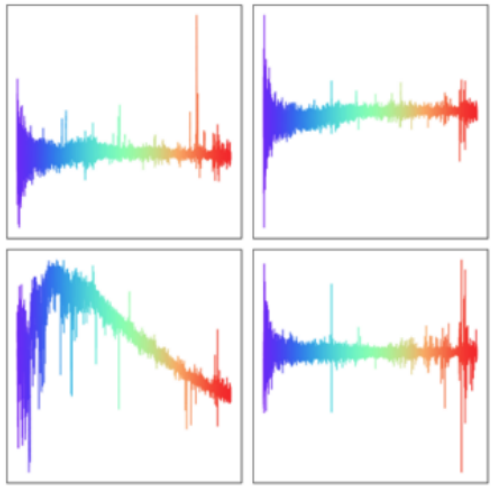
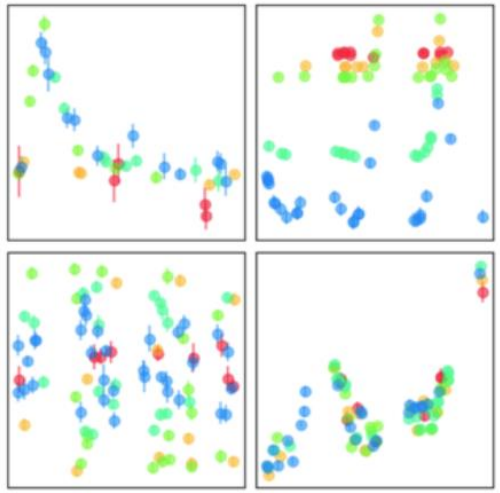
The Multimodal Universe Collaboration et al. 2024







图片
形态信息

光谱
特征线信息

光变曲线
时序信息

Rizhko et al. 2024

Feature	Description
mean_vmag	Mean magnitude in the visible band
phot_g_mean_mag	Gaia G-band mean magnitude
e_phot_g_mean_mag	Uncertainty in Gaia G-band mean magnitude
phot_bp_mean_mag	Gaia BP band mean magnitude
e_phot_bp_mean_mag	Uncertainty in Gaia BP band mean magnitude
phot_rp_mean_mag	Gaia RP band mean magnitude
e_phot_rp_mean_mag	Uncertainty in Gaia RP band mean magnitude
bp_rp	BP mean magnitude minus RP mean magnitude
parallax	Gaia DR3 Parallax measurement
parallax_error	Uncertainty in parallax measurement
parallax_over_error	Signal-to-noise ratio for parallax measurement

星表
测光、自行信息

多模态信息互补，丰富特征

有助于提高测光红移测量的精度

数据集构建 ELG样本

National Astronomical Data Center 国家天文科学数据中心

Table 1. Information about the various spectroscopic surveys included in the dataset. $\tilde{z}_{spec}$ denotes the median of z_{spec}. $\tilde{r}$(mag) denotes the median of r-band magnitude.

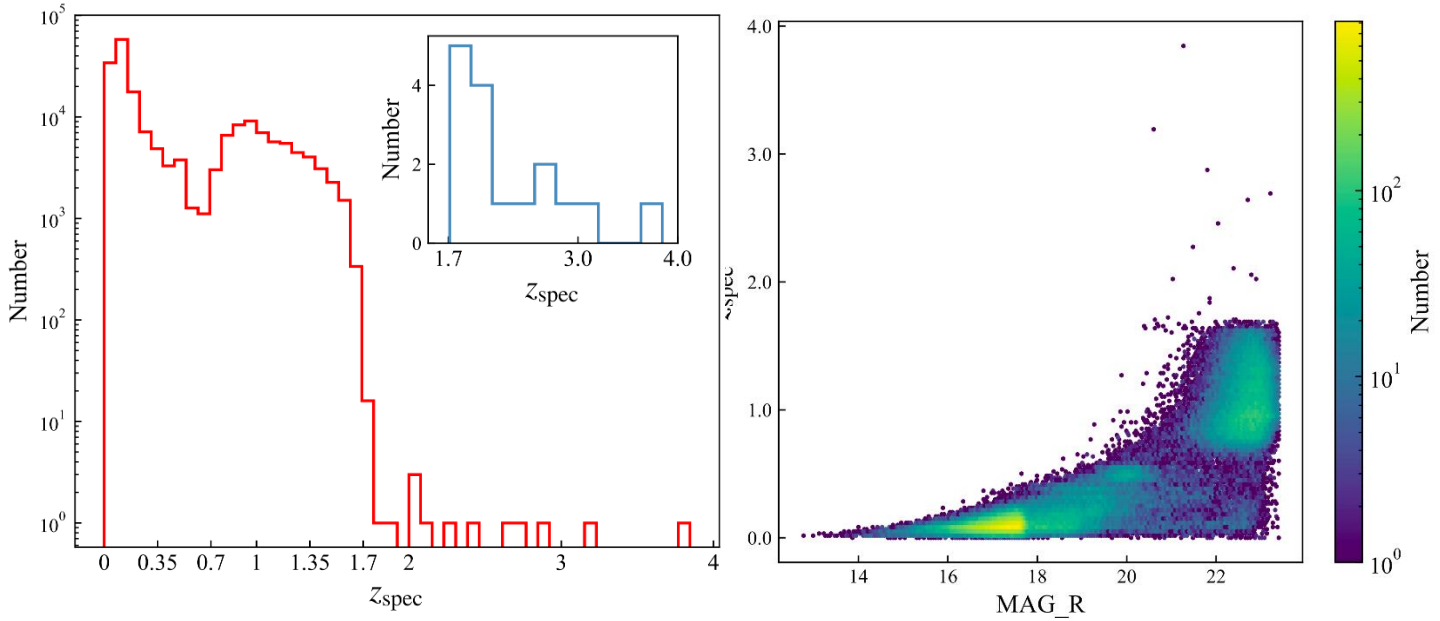
Survey	No. of sources	Quality criterion	$\tilde{z}_{spec}$	$\tilde{r}$(mag)
SDSS	122 452	zWarning=0	0.11	17.48
DESI SV3	52 491	zWarning=0, ZERR<0.01	1.04	22.73
DESI SV1	10 782	zWarning=0, ZERR<0.01	0.94	22.63
dFGRS	3 220	Q=3,4	0.06	15.57
PRIMUS	909	ZQUALITY=3,4	0.56	21.37
zCOSMOS	716	5≥CC≥3	0.68	21.67
LAMOST	612	Z_ERR≤ 0.01	0.12	16.98
GAMA	442	NQ=4	0.19	18.78
VIPERS	274	zflag=3,4	0.79	21.83
WiggleZ	118	qz=4,5	0.63	20.90
VVDS	109	ZFLAGS=4	0.74	22.13
fCOSMOS	103	ZFLAG ≥ 3	1.48	22.73
dFGRS	88	Q=4	0.11	17.38
OzDES	28	qop=4	0.46	20.46
C3R2	19	Qual≥3	0.82	22.43
DEEP2	12	ZQUALITY≥3	0.82	22.67
Total No.	192 375		0.16	18.41

SIMBAD: AGN / EmG

STARFORMING / STARBURST / AGN / BROADLINE

ELG

训练：验证：测试
144663: 9237: 38475



数据集构建 LS DR10 多波段图像

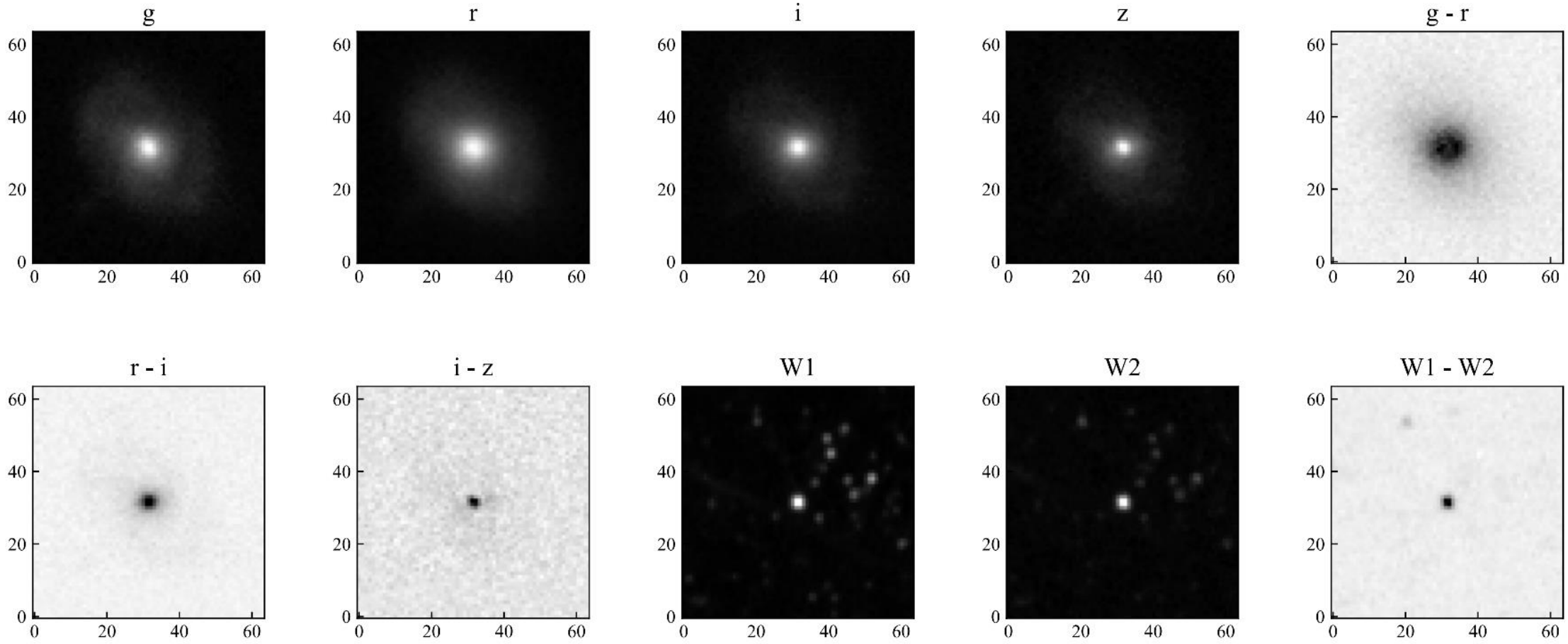


Figure 4. Example multi-band images of a single ELG source with a z_{spec} of 0.156 from the dataset. The 64 × 64 imaging data consist of 10 channels, with the bands ordered from optical to infrared. Notable resolution discrepancies are observed between the optical and infrared images.

数据集构建 LS DR10星表

Table 2. Photometric data corresponding to the known ELG dataset.

Name	Definition	Catalogue	Waveband
MAG_G	Model magnitude in *g* band	DESI	Optical band
MAG_R	Model magnitude in *r* band	DESI	Optical band
MAG_I	Model magnitude in *i* band	DESI	Optical band
MAG_Z	Model magnitude in *z* band	DESI	Optical band
MAG_W1	Model magnitude in *W*1 band	DESI	Infrared band
MAG_W2	Model magnitude in *W*2 band	DESI	Infrared band
APMAG_G_(1∼8)[a]	Aperture magnitude in *g* band	DESI	Optical band
APMAG_R_(1∼8)	Aperture magnitude in *r* band	DESI	Optical band
APMAG_I_(1∼8)	Aperture magnitude in *i* band	DESI	Optical band
APMAG_Z_(1∼8)	Aperture magnitude in *z* band	DESI	Optical band
APMAG_W1_(1∼5)[b]	Aperture magnitude in *W*1 band	DESI	Infrared band
APMAG_W2_(1∼5)	Aperture magnitude in *W*2 band	DESI	Infrared band
ebv	Galactic extinction E(B-V) reddening	DESI	
z_spec	Spectroscopic redshift	Known sample	

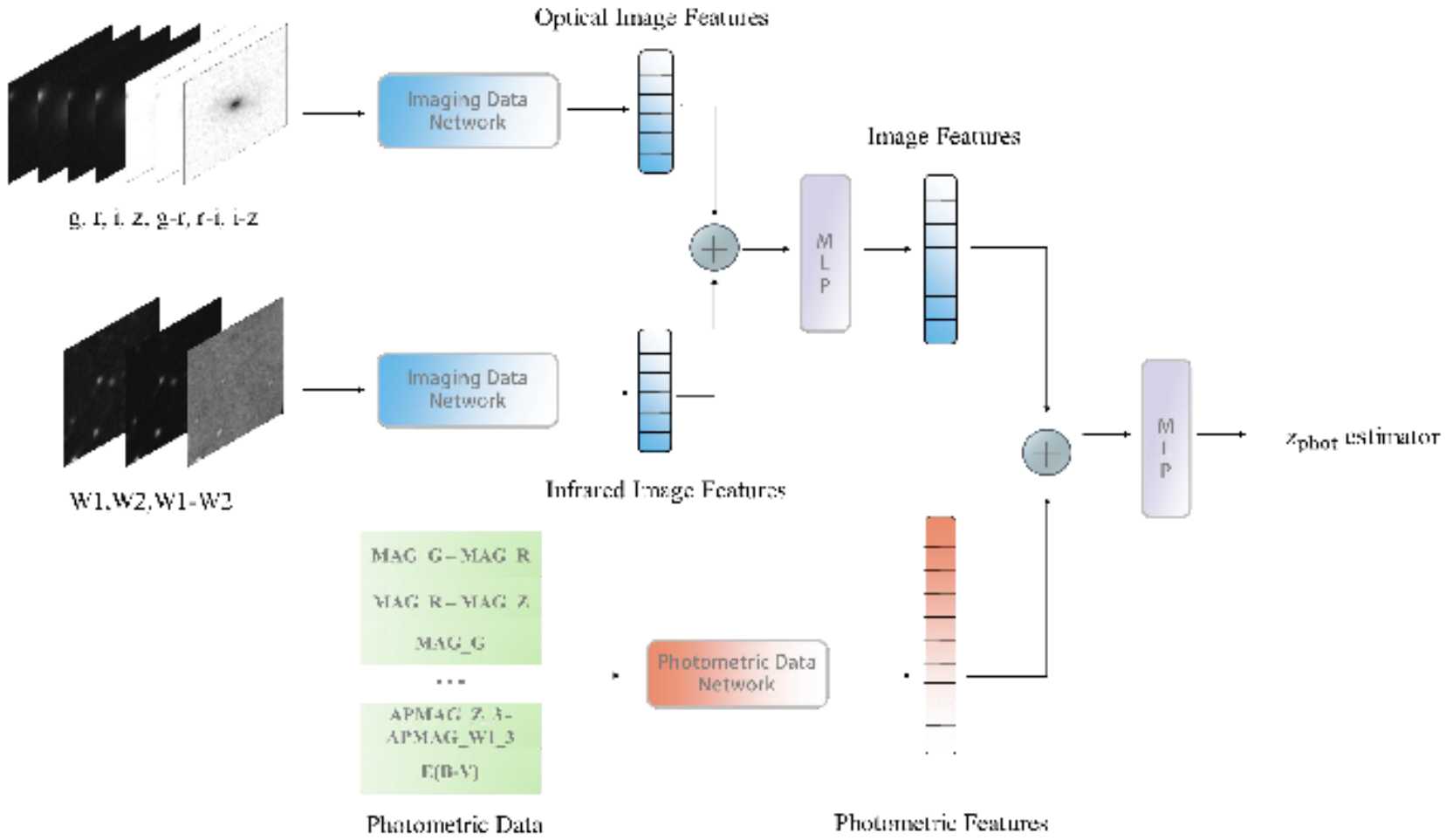
[a]Optical aperture magnitude suffixes 1∼8 correspond to fluxes measured within circular apertures of radii [0.5, 0.75, 1.0, 1.5, 2.0, 3.5, 5.0, 7.0] arcsec.
[b]Infrared aperture magnitude suffixes 1∼5 correspond to apertures with radii [3, 5, 7, 9, 11] arcsec.

模型、孔径星等
模型星等颜色：MAG_G - MAG_R
孔径星等颜色:
APMAG_G_1 - APMAG_R_1

Appendix A.2. List of selected photometric features

The 85 photometric features from the DESI LS10 catalogue ranked by PFI, used as the input to the model are as follows: $MAG\_R - MAG\_W2$, $MAG\_I - MAG\_W1$, $MAG\_R - MAG\_W1$, $MAG\_I - MAG\_W2$, $MAG\_Z - MAG\_W1$, $-MAG\_R - MAG\_I$, $MAG\_G - MAG\_W2$, $MAG\_Z - MAG\_W2$, $MAG\_G - MAG\_R$, $MAG\_I - MAG\_Z$, $MAG\_G - MAG\_I$, $APMAG\_W1\_2 - APMAG\_W2\_2$, $MAG\_R - APMAG\_R\_1$, $MAG\_R - MAG\_Z$, $MAG\_G - APMAG\_G\_1$, $APMAG\_Z\_5 - APMAG\_W1\_5$, MAG_G, $MAG\_G - MAG\_W1$, $MAG\_I - APMAG\_I\_1$, $APMAG\_W1\_3 - APMAG\_W2\_3$, MAG_I, MAG_Z, $APMAG\_I\_7 - APMAG\_Z\_7$, $MAG\_Z - APMAG\_Z\_1$, $APMAG\_R\_6 - APMAG\_I\_6$, $APMAG\_I\_6 - APMAG\_Z\_6$,

模型构建　多模态模型



CNN – MLP

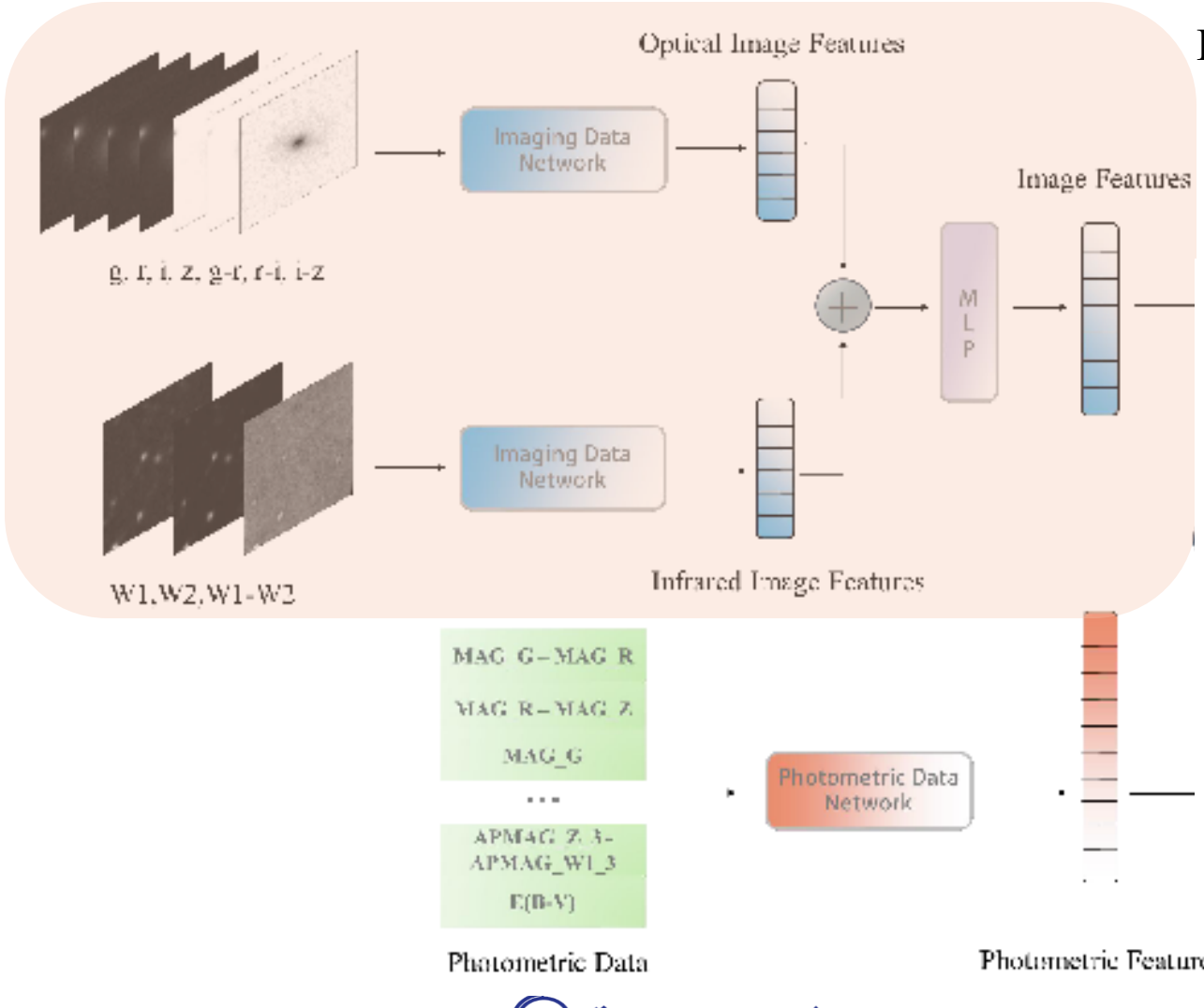
多波段图像：Inception

星表：MLP

模态融合：特征拼接

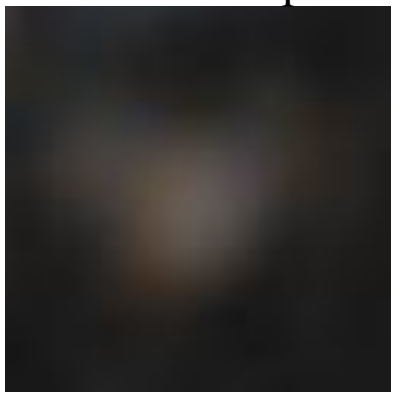
红移估计：MLP

模型构建　图像模块

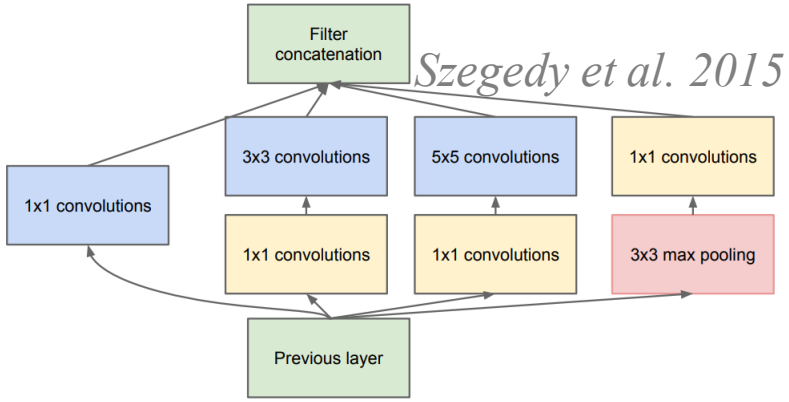


DESI LS 0.262”/pixel

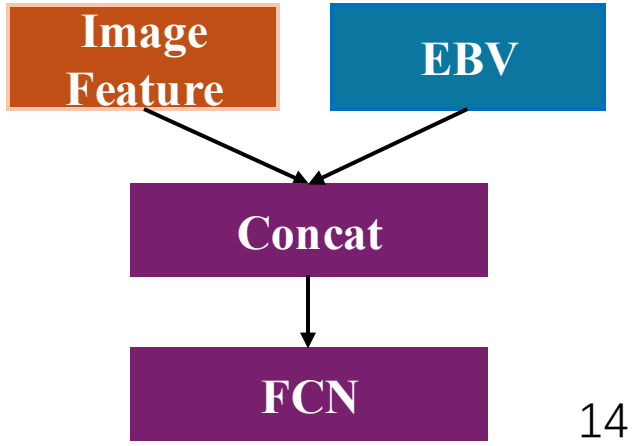
WISE 2.75”/pixel



图像模型 Inception



考虑消光



模型构建　红移估计模块

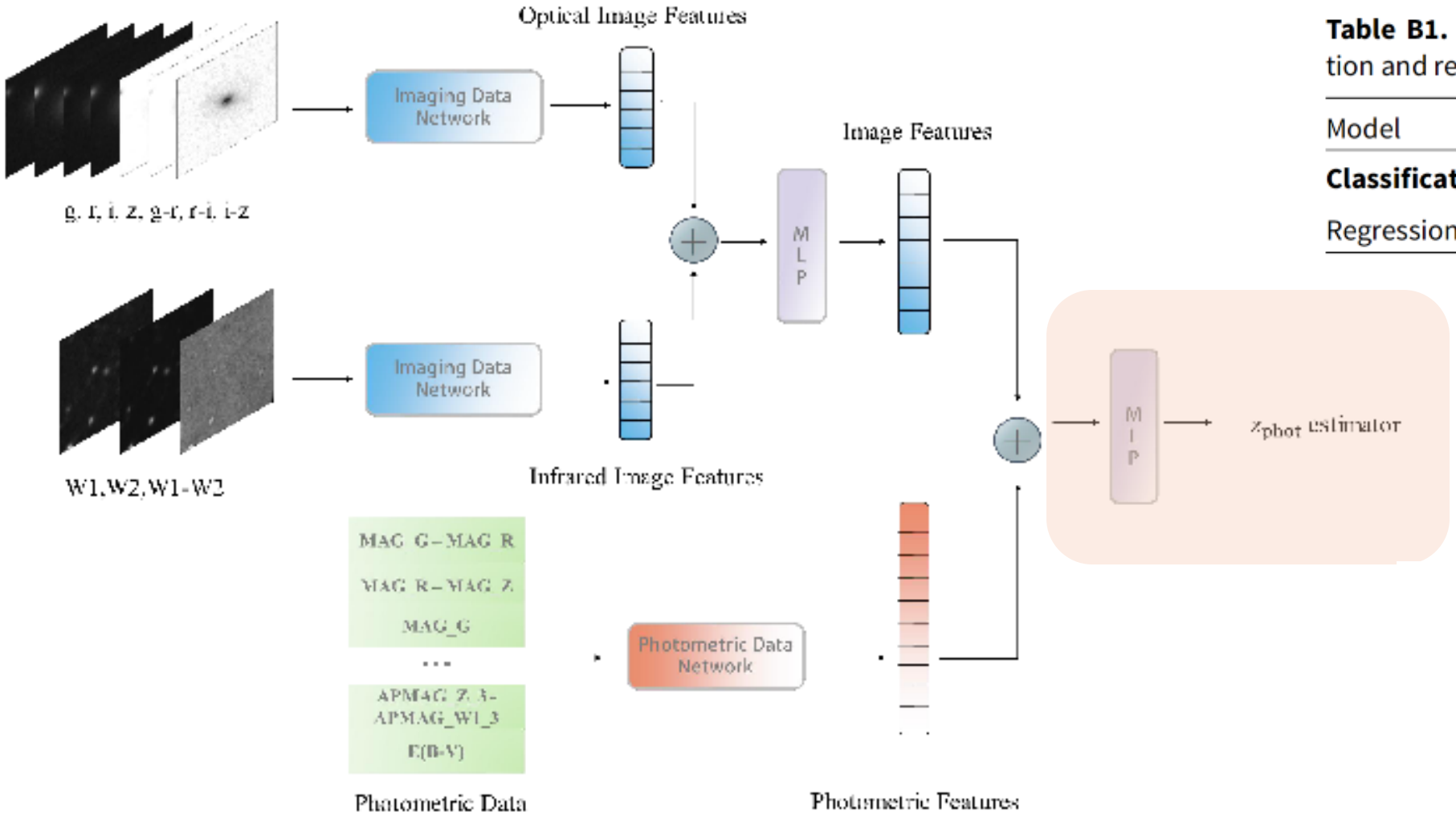
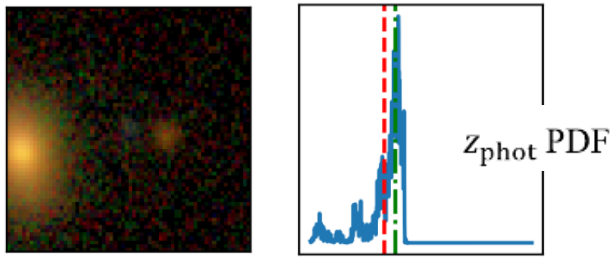


Table B1. Performance comparison for classification and regression approaches.

Model	Bias	σ_{NMAD}	η
Classification	**0.0002**	**0.0140**	**0.0257**
Regression	−0.0025	0.0222	0.0259

pred(r):1.29 true(g):1.477



$$z_{\text{phot}} = \sum_{k=1}^{N_c} z_k P(z_k)$$

实验结果

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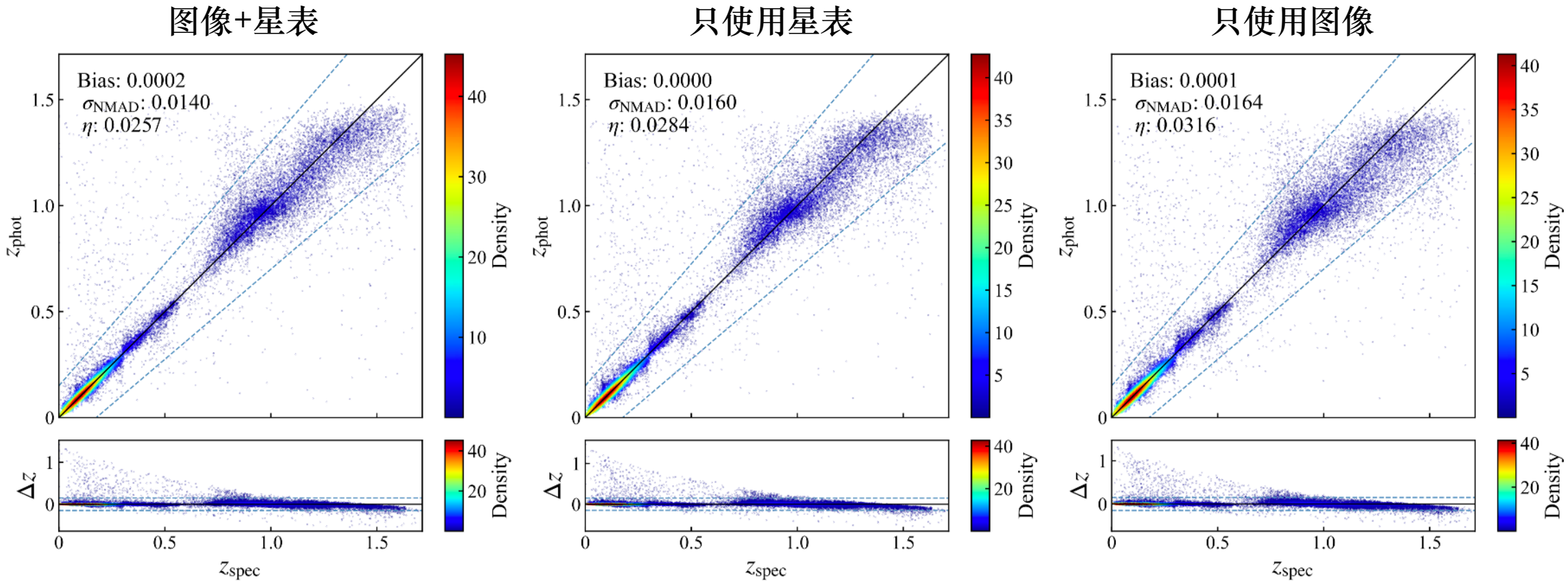
结合**多模态**数据提供的互补信息有助于ELG测光红移估计效果的**提升**



实验结果

National Astronomical Data Center
国家天文科学数据中心

模型在**低红移**和**亮源**上对于测光红移估计的准确度较高

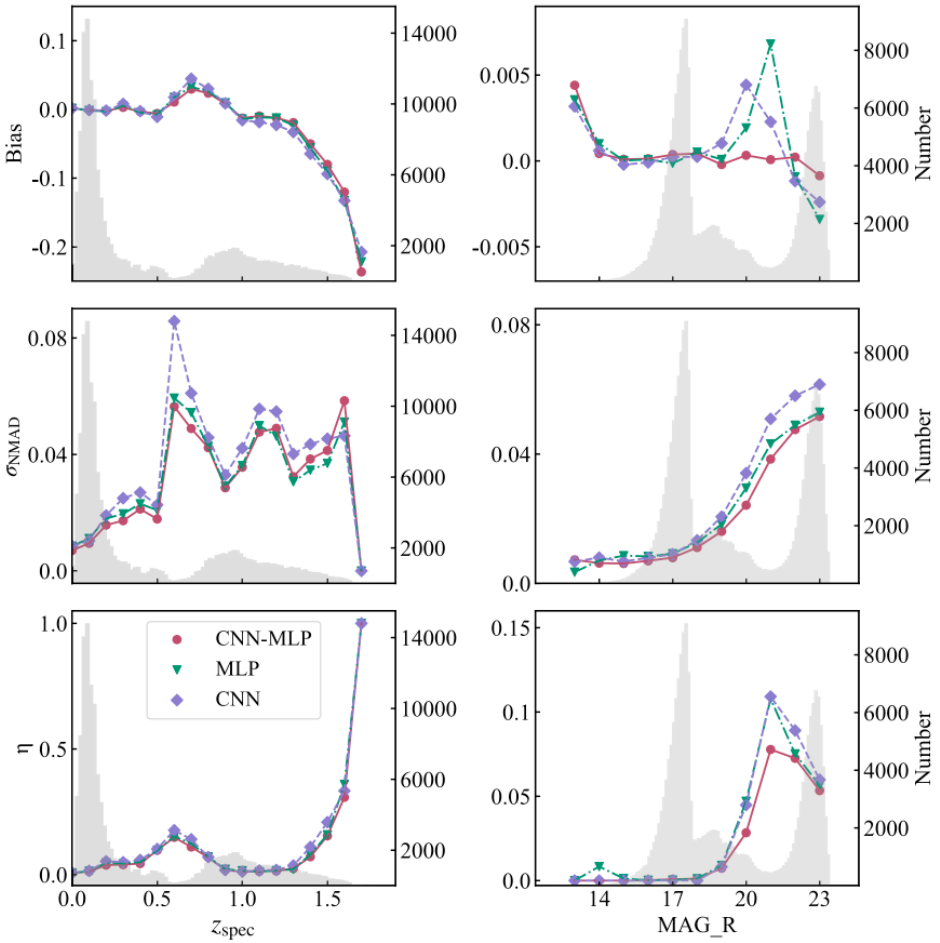
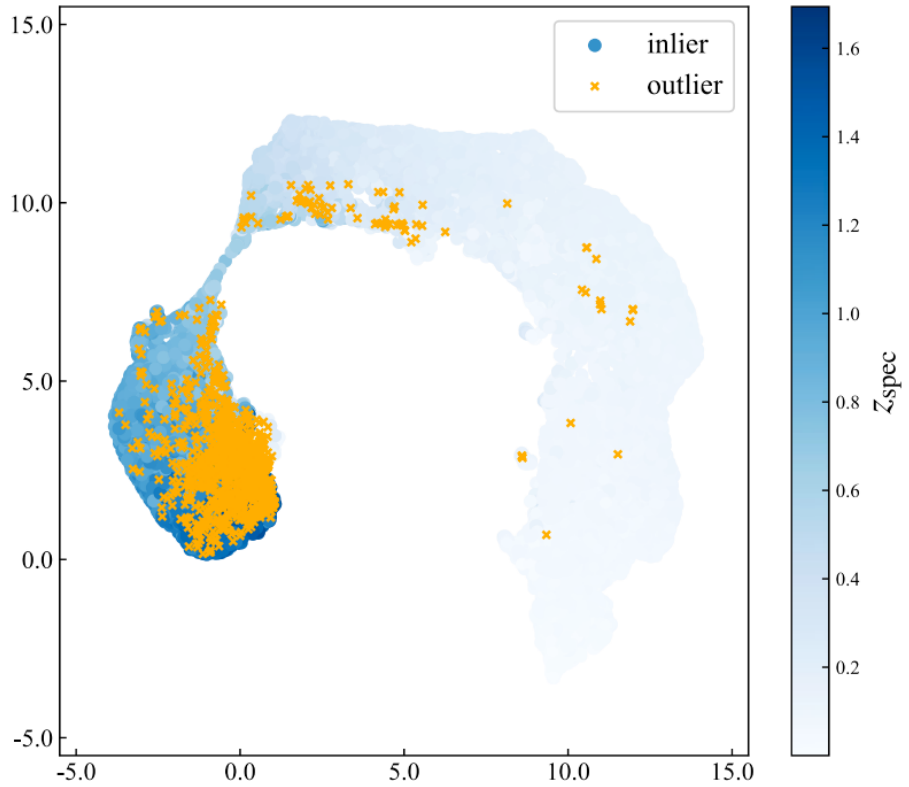


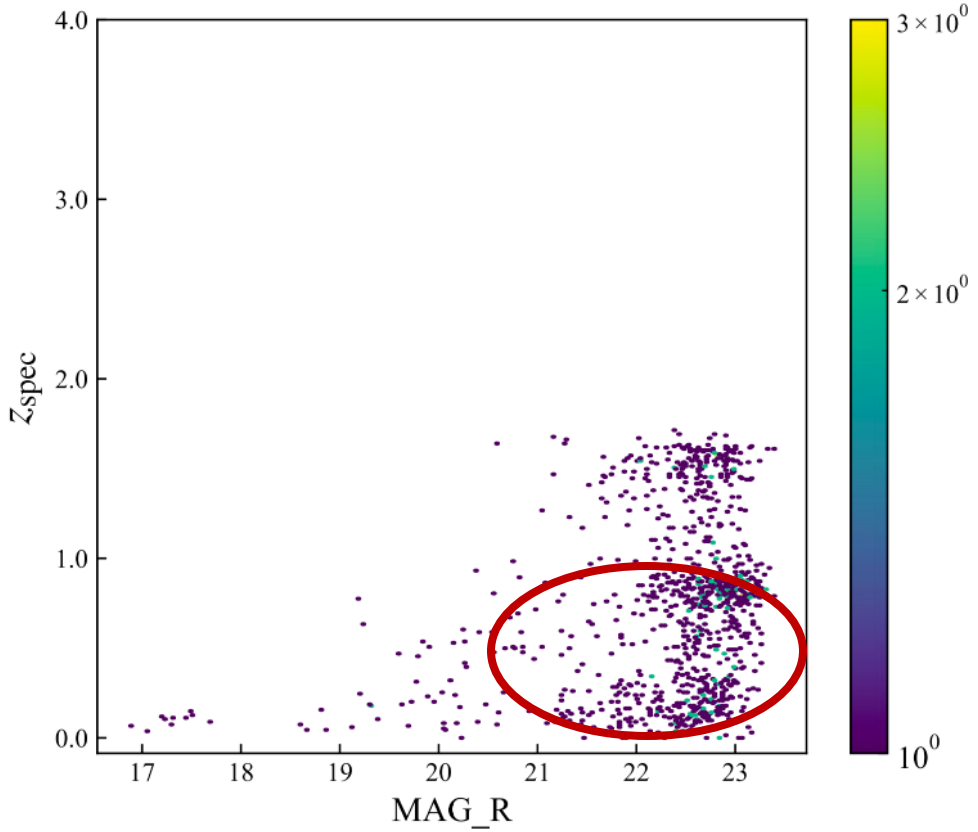
Table 5. Performance of bright and faint sources using the two-part model and one-part model.

Model	Sources	Bias	σ_{NMAD}	η
Two-part model	$MAG\_R < 21.5$	0.0000	0.0089	0.0044
	$MAG\_R > 21.5$	0.0010	0.0494	0.0715
	All	0.0001	0.0139	0.0270
One-part model	$MAG\_R < 21.5$	0.0003	0.0090	0.0041
	$MAG\_R > 21.5$	0.0000	0.0479	0.0691
	All	0.0002	0.0140	0.0257

实验结果

部分**离群点**来自**低红移和暗源**的简并性





实验结果

National Astronomical Data Center
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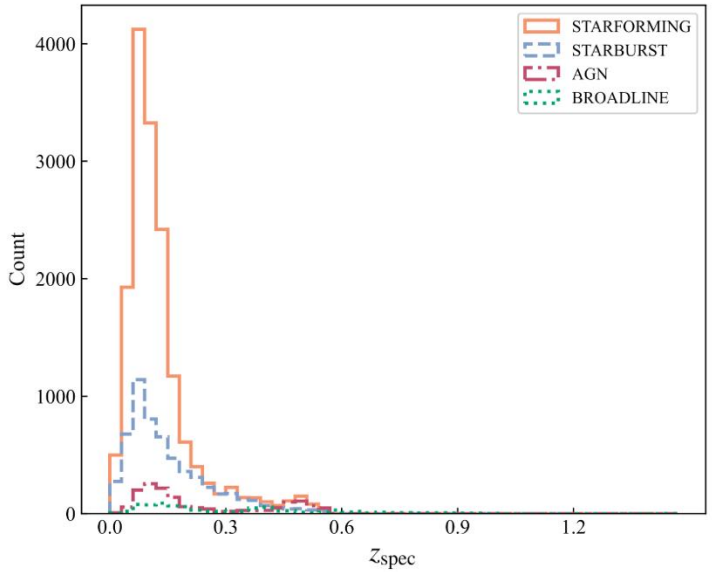
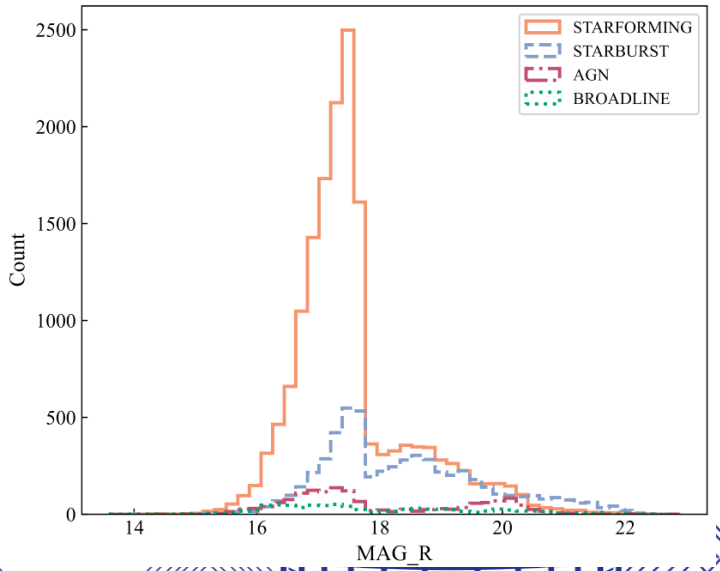
发射线星系类型对于模型效果无较大差异

Table 6. Performance for different galaxy types.

Galaxy type	No. of sources	Bias	σ_{NMAD}	η
Starforming	15 944	0.0003	0.0083	0.0023
Starburst	5 738	0.0003	0.0101	0.0052
AGN	1 512	0.0030	0.0134	0.0040
Broadline	803	−0.0027	0.0103	0.0050
All	23 997	0.0003	0.0090	0.0032





总结

- ✓ 构建CNN-MLP模型整合多波段测光图像和测光星表多模态天文数据
- ✓ 提高DESI Legacy Imaging Surveys 发射线星系的测光红移预测精度
- ✓ 为DESI及后续大型巡天项目ELG选源和测光红移测量提供参考

论文

Wei et al. 2025, PASA
arXiv:2505.24175

代码

https://github.com/RuiNov1st/Zphot4ELG